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Anatomical Variations of the Sciatic Nerve Divisions in Relation to the Piriformis Muscle and Clinical Implications

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ANATOMICAL VARIATIONS OF THE SCIATIC NERVE DIVISIONS IN RELATION TO THE PIRIFORMIS MUSCLE AND CLINICAL IMPLICATIONS

by

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ANATOMICAL VARIATIONS OF THE SCIATIC NERVE DIVISIONS IN RELATION TO THE PIRIFORMIS MUSCLE AND CLINICAL IMPLICATIONS

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University of Nebraska, 2017

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The goal of this project was to identify and quantify the anatomical variations of the sciatic nerve divisions in relation to the piriformis muscle and compare the data collected to the primary literature. This was done in an effort to provide awareness of sciatic nerve entrapments within the subgluteal space that may be responsible for posterior hip and buttock pain. While the current means of diagnosis are through physical examination, imaging techniques, and surgery, the results of this present study indicate that new methods of diagnosis need to be explored.

TABLE OF CONTENTS

ACKNOWLEDGMENTS ii
ABSTRACT iii
LIST OF FIGURES vi
LIST OF TABLES vii
CHAPTER 1: INTRODUCTION 1
ANATOMY 2
HIP JOINT 2
GLUTEAL REGION 7
MUSCLES OF THE GLUTEAL REGION 7
GREATER SCIATIC FORAMEN 9
MUSCLES RELATED TO THE GREATER SCIATIC FORAMEN 9
NERVES OF THE GLUTEAL REGION 11
ARTERIES OF THE GLUTEAL REGION 14
SCIATIC NERVE KINEMATICS WITHIN THE SUBGLUTEAL SPACE 16
POSTERIOR HIP AND BUTTOCK PAIN ETIOLOGY 18
DEEP GLUTEAL SYNDROME 18
FIBROUS AND FIBROVASCULAR BANDS 19
PIRIFORMIS SYNDROME 21
GEMELLI-OBTURATOR INTERNUS SYNDROME 24
QUADRATUS FEMORIS MUSCLE AND ISCHIOFEMORAL PATHOLOGY 24
HAMSTRING CONDITION 24
CONCLUSION 24
CHAPTER 2: METHODS 26
CADAVERIC DONORS 26
DISSECTION AND DATA COLLECTION PROCEDURE 27
STATISTICS 28
CHAPTER 3: RESULTS 29
ADULT CADAVERIC STUDIES (PRIMARY LITERATURE) 34
NATIONALITY AND REGIONAL COMPARISONS 36
FETAL CADAVERIC STUDIES (PRIMARY LITERATURE) 40
SURGICAL STUDIES 44
PRESENT STUDY 48
CHAPTER 4: DISCUSSION 59
LIMITATIONS 60
IMAGING 60

STUDENT DISSECTIONS 60

MEDICAL HISTORY 61

PREVALENCE AND LATERALITY OF VARIATIONS BASED ON SEX 61

NATIONALITY AND REGIONAL COMPARISONS OF ADULT CADAVERIC STUDIES (PRIMARY LITERATURE) 61

FETAL CADAVERIC STUDIES (PRIMARY LITERATURE) 62

SURGICAL STUDIES 62

PRESENT STUDY 62

CONCLUSION 63

BIBLIOGRAPHY 65

APPENDICES 69

APPENDIX A: INTERACTIVE DISSECTION GUIDE 70

APPENDIX B: BEQUETHAL FORM 72

APPENDIX C: PRESENT STUDY SOURCE DATA 80

LIST OF FIGURES

Figure 1: Joint motions of the hip (Kirkham, 2014). 3

Figure 2: Ligaments of the hip joint (Jones, 2017). 5

Figure 3: Gluteal lines (University of Glasgow, n.d.). 8

Figure 4: Muscles of the gluteal region. Abductors and lateral rotators (Moore, et al., Clinically Oriented Anatomy, 2014, p. 564). 10

Figure 5: Nerves of the gluteal and posterior thigh regions (Moore, et al., Clinically Oriented Anatomy, 2014, p. 573). 13

Figure 6: Arteries of the gluteal and posterior thigh regions (Moore, et al., Clinically Oriented Anatomy, 2014, p. 576). 15

Figure 7 a-d: Pathogenic classification of fibrous/fibrovascular bands. (a, b) Compressive or bridge-type bands limiting the movement of the sciatic nerve from anterior to posterior (type 1A) or from posterior to anterior (type 1B). (c, d) Adhesive or horse-strap bands (type 2), which bind strongly to the sciatic nerve structure, anchoring it in a single direction. They can be attached to the sciatic nerve laterally (type 2A) or medially (type 2B) (Hernando, et al., 2015). 20

Figure 8 a-f: Anatomic variations of the relationship between the piriformis muscle and sciatic nerve. Diagrams illustrate the six variants, originally described by Beaton and Anson. (a) An undivided nerve comes out below the piriformis muscle (normal course). (b) A divided sciatic nerve passing through and below the piriformis muscle. (c) A divided nerve passing above and below an undivided muscle. (d) An undivided sciatic nerve passing through the piriformis muscle. (e) A divided nerve passing through and above the muscle heads. (f) Diagram showing an unreported additional B-type variation consisting of a smaller accessory piriformis (AP) with its own separate tendon. SN sciatic nerve, P piriformis muscle, SG superior gemellus muscle (Hernando, et al., 2015). 23

Figure 9: Undivided sciatic nerve below undivided piriformis muscle. This image was obtained during the present study. 32

Figure 10: Divisions of the sciatic nerve between (common peroneal nerve) and below (tibial nerve) the piriformis muscle. This image was obtained during the present study. 33

LIST OF TABLES

Table 1: Joint motions and associated muscles. 4

Table 2: Ligaments of the hip joint. 6

Table 3: Subgluteal space borders. 17

Table 4: Classification Systems: Additional classification systems compared to Beaton & Anson's. The descriptions in the table are the original ones used by Beaton & Anson. 22

Table 5: Normal and anomalous limb percentages for the present study and for adult cadaveric studies (primary literature). 31

Table 6: Primary literature values for adult cadaveric studies. Trotter (1932) and Fishman, et al. (2002) Studies highlighted in yellow did not report the number of anomalies separately, but as the total number of limbs with variations B-F. 35

Table 7: Regional Comparison of Adult Cadaveric Studies (Primary Literature). The present study involved cadavers from the United States and is included in the table below. 37

Table 8: Eastern Asia (Adult Cadaveric Studies) vs. Other Regions Examined (Adult Cadaveric Studies) 39

Table 9: Primary literature values for fetal cadaveric studies. 41

Table 10: Fetal Cadaveric Studies (Primary Literature) vs. Adult Cadaveric Studies (Eastern Asia Excluded) 43

Table 11: Prevalence of piriformis and sciatic nerve division variations in published surgical studies for piriformis syndrome. 45

Table 12: Surgical Studies vs. Adult Cadaveric Studies (Eastern Asia Excluded) 47

Table 13: Present Study vs. Adult Cadaveric Studies (Eastern Asia Excluded) 49

Table 14: Present Study vs. Adult Cadaveric Studies (American) 51

Table 15: Present Study vs. Adult Cadaveric Studies (European) 53

Table 16: Present Study vs. Fetal Cadaveric Studies (Primary Literature) 55

Table 17: Present Study vs. Surgical Studies 57

Table 18: Source data obtained during the present study 80

CHAPTER 1: INTRODUCTION

There are 1.5 billion people worldwide who suffer from chronic pain according to a market research report (Global Industry Analysts, Inc., 2011). Pain is associated with a wide range of injury and disease and is sometimes the disease itself. When asked about four common types of pain, respondents of a National Institute of Health Statistics survey indicated that low back pain was the most common (27%), followed by severe headache or migraine pain (15%), neck pain (15%) and facial ache or pain (4%) (U.S. Department of Health and Human Services, 2006). Fifty-five percent of Americans feel that pain research and management should be a high priority for the medical community. Almost six in ten adults (57%) say they would be willing to pay one dollar more per week in taxes to increase federal funding for the scientific research into the causes and treatment of pain (Peter D. Hart Research Associates, 2003). These statistics illustrate the demand for continued research and focus on pain.

Hip pain affects patients of all ages and can have a significant effect on quality of life. The literature reviewed below examines the potential sources of posterior hip and buttock pain with an emphasis on the anatomical variations of the sciatic nerve divisions in relation to the piriformis muscle and its associated entrapments within the subgluteal space. Continued research into the cause of hip pain is important because approximately 14% of patients 60 years and older reported significant hip pain on most days over the previous six weeks (Cecchi, et al., 2008). Additionally, by 2050, people over the age of 60 are expected to account for 25-29% of the U.S. population (HelpAge International, 2013). This data suggests that the number of patients with hip pain will continue to rise. This creates a sense of urgency to identify the root cause of hip pain to decrease healthcare costs and enable providers to accurately diagnose and treat patients.

The goal of this project was to identify the anatomical variation divisions of the sciatic nerve in relation to the piriformis muscle. The present research into these anatomical variations will supplement existing data, provide awareness of additional sciatic nerve entrapments, and aid in the research of potential etiologies of pain, specifically, posterior hip and buttock pain. The present study sought to compare data from primary literature to data collected to identify the prevalence of anatomical variations in a given population.

ANATOMY

To understand the various etiologies of posterior hip and buttock pain it is important to review the normal anatomy and function of the hip joint and gluteal region. Detail will be given to the sciatic nerve in an area known as the subgluteal space, also known as the deep gluteal space. Entrapment of the nerve as it passes through this space plays an important role in posterior hip and buttock pain. Anatomical variations and their associated entrapments should also be considered. These variations may be discovered through physical examination, imaging techniques such as MRI, or during surgery.

HIP JOINT

The hip joint, also called the acetabulofemoral or femoroacetablular joint, is a ball-and-socket synovial joint that is between the acetabulum of the pelvis and the femur. It is the strongest and most stable joint in the human body due to its extensive articular surface contact, strong joint capsule, and its many surrounding muscles. Its function is to allow multiaxial motion while supporting the weight of the body in both static and dynamic postures as shown in **Figure 1** (Kishner, 2015). The joint motions and associated muscles are summarized in **Table 1** and the ligaments of the hip joint are shown in **Figure 2** and summarized in **Table 2**.

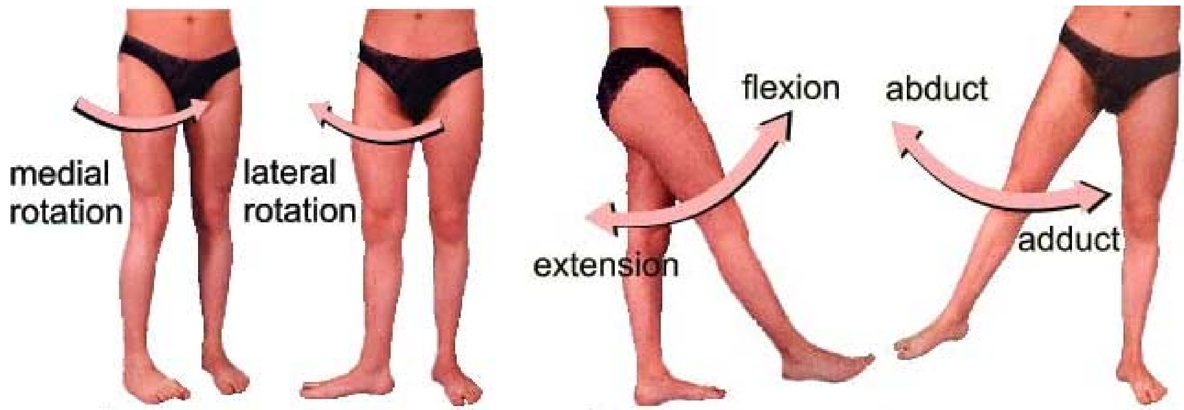

Figure 1: Joint motions of the hip (Kirkham, 2014)***.***

Table 1: Joint motions and associated muscles.

Joint Motion	Primary Movers	Stabilizing and Helping Movers
Flexion	Iliopsoas, Sartorius, Tensor fasciae latae, Rectus femoris, Adductor longus, Pectineus	Adductor brevis, Gracilis, Gluteus minimus (anterior fibers)
Extension	Gluteus maximus, Biceps femoris (long head), Semitendinosus, Semimembranosus, Adductor magnus (posterior head)	Gluteus medius (posterior fibers), Adductor magnus (anterior head)
Abduction	Gluteus medius, Gluteus minimus, Tensor fasciae latae	Piriformis, Sartorius
Adduction	Pectineus, Adductor longus, Gracilis, Adductor brevis, Adductor magnus	Biceps femoris (long head), Gluteus maximus (lower fibers), Quadratus femoris
Medial (Internal) Rotation	N/A	Biceps femoris (anterior fibers), Gluteus medius (anterior fibers), Tensor fasciae latae, Adductor longus, Adductor brevis, Pectineus
Lateral (External) Rotation	Gluteus maximus, Piriformis, Obturator internus, Superior gemellus, Inferior gemellus, Quadratus femoris	Gluteus medius (posterior fibers), Gluteus minimus (posterior fibers), Obturator externus, Sartorius, Biceps femoris (long head)

(Child, et al., 2015)

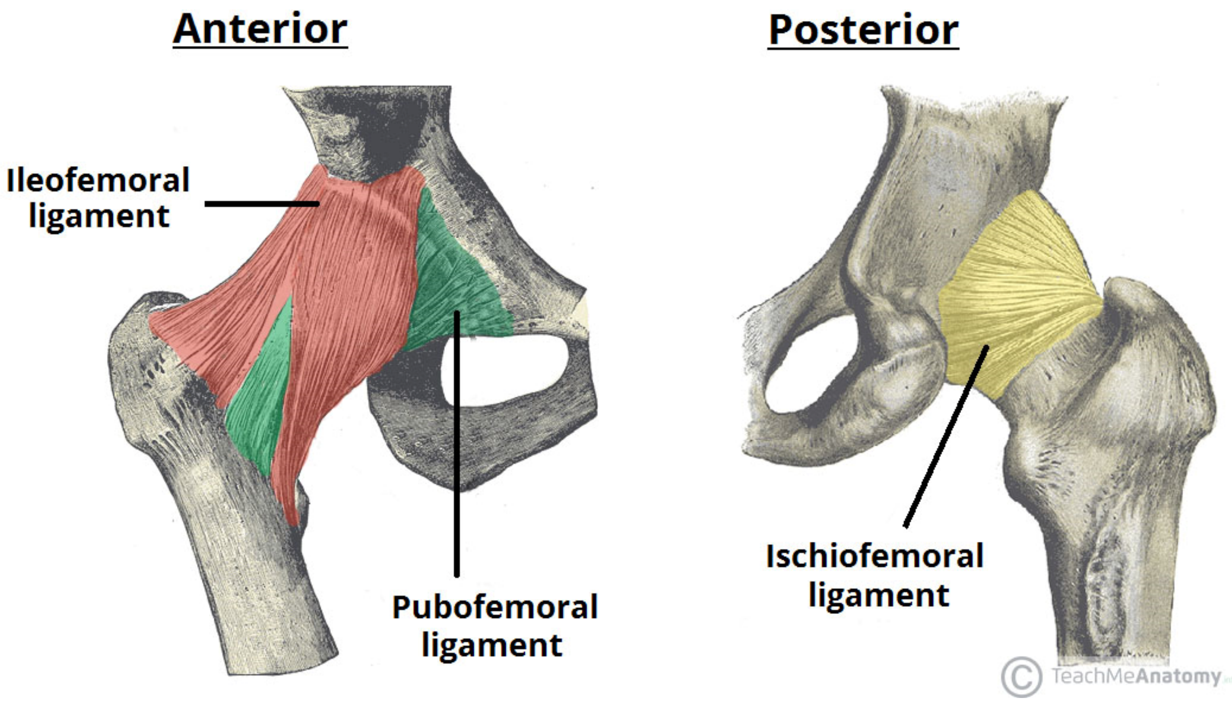

Figure 2: Ligaments of the hip joint (Jones, 2017)**.**

Table 2: Ligaments of the hip joint.

Ligament	Attachments	Function	Other Associated Joint Constraints
Iliofemoral (Y-ligament)	Near the anterior inferior iliac spine and adjacent margin of the acetabulum to the intertrochanteric line of the femur	Stabilizing and strengthening the anterior aspect of the joint capsule	Resist excessive motion into hip extension and external rotation
Pubofemoral	Anterior and inferior rim of the acetabulum and adjacent portions of superior pubic ramus and obturator membrane to mix with the Iliofemoral ligament on the intertrochanteric line of the femur	Stabilizing and strengthening the anterior aspect of the joint capsule	Resist excessive motion into hip abduction, extension, and lesser amount into external rotation
Ischiofemoral	Posterior, inferior aspect of the acetabulum to the greater trochanter and femoral neck	Stabilizing and strengthening the posterior aspect of the joint capsule	Resist excessive motion into internal rotation, extension, and adduction
Transverse Acetabular	Continuation of the acetabular labrum	Join the ends of the acetabular labrum passing over the acetabular notch	N/A
Ligamentum Teres (Ligament of the head of the femur)	Both sides of the outer edge of the acetabular notch to fovea of the femur and slight mixing with transverse acetabular ligament	Passageway for the obturator neurovasculature	Taut in semi-flexion and adduction

(Child, et al., 2015)

GLUTEAL REGION

The gluteal region lies on the posterolateral aspect of the pelvis. It is occupied by large powerful muscles. Several important nerves and vessels traverse this area.

MUSCLES OF THE GLUTEAL REGION

The gluteus maximus is the largest and most superficial muscle in the gluteal region. It has an extensive origin from the lateral surface of the ala of the ilium that is posterior to the posterior gluteal line. It also originates from the posterior surface of the sacrum and coccyx and the sacrotuberous ligament. It is composed of coarse fibers that run obliquely downwards and laterally behind the hip joint. Most of the muscle inserts into the iliotibial tract. The gluteus maximus muscle extends and laterally rotates the hip joint. Just deep to the gluteus maximus is the gluteus medius muscle. It originates from the lateral surface (gluteal surface) of the ilium between the anterior and posterior gluteal lines (**Figure 3**). It runs above the hip joint and inserts onto the lateral aspect of the greater trochanter. The gluteus medius muscle abducts the hip joint. The last of the gluteal muscles is the gluteus minimus which lies beneath the gluteus medius. It originates from the lateral surface of the ilium between the anterior and inferior gluteal lines (**Figure 3**). It inserts onto the anterior aspect of the greater trochanter of the femur (Moore, et al., Clinically Oriented Anatomy, 2014).

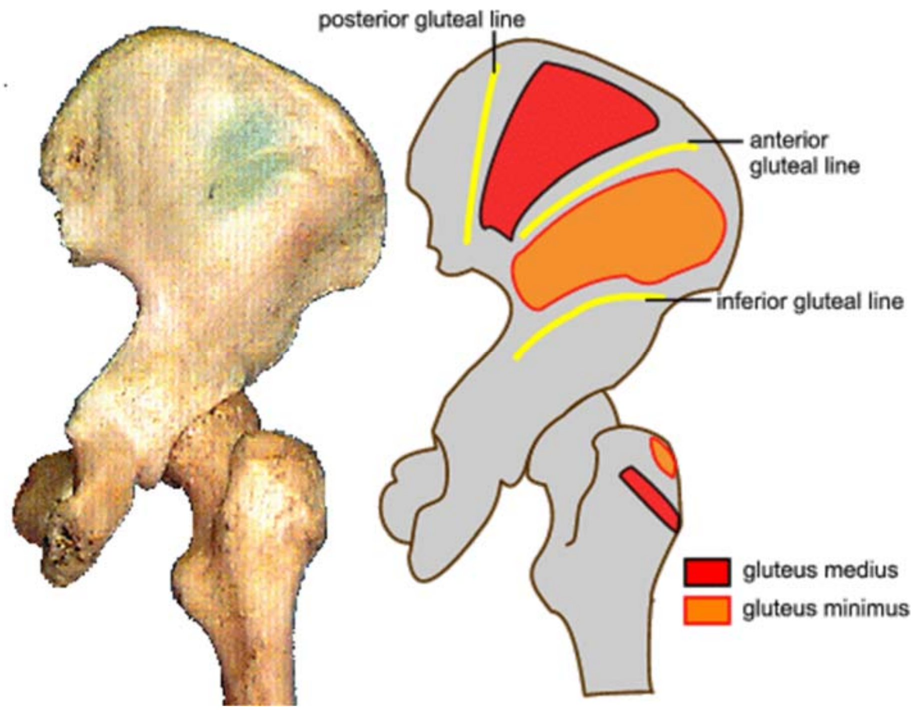

Figure 3: Gluteal lines (University of Glasgow, n.d.)**.**

GREATER SCIATIC FORAMEN

The greater sciatic foramen is one of the major gateways between the pelvic cavity and the lower limb. It is formed by the greater sciatic notch and the sacrospinous ligament attaching to the ischial spine. There are several muscles, arteries, veins, and nerves that pass through the greater sciatic foramen (Bierry, et al., 2014).

MUSCLES RELATED TO THE GREATER SCIATIC FORAMEN

The piriformis muscle lies centrally in the gluteal region. It originates from the anterior surface of the lateral process of the sacrum and the dorsal aspect of the ilium around the margin of the greater sciatic notch. It inserts onto the upper border of the greater trochanter. It externally rotates the hip joint when the thigh is extended. The obturator internus muscle originates from the inner surface of the obturator membrane and contiguous bone. It has a common insertion with the superior and inferior gemelli muscles which is onto the medial aspect of the greater trochanter of the femur. The superior gemellus muscle originates from a small area on the outer surface of the hip bone below the ischial spine. The inferior gemellus muscle originates from the superior aspect of the ischial tuberosity. They share a common insertion with the obturator internus muscle via the tricipital tendon. The quadratus femoris muscle originates from the lateral aspect of the ischial tuberosity. It inserts onto the quadrate tubercle on the intertrochanteric crest and the adjacent area of the posterior femur. The superior gemellus, inferior gemellus, obturator internus, and quadratus femoris muscles are collectively known as the short lateral rotators of the hip joint (**Figure 4**) (Martin, et al., 2014).

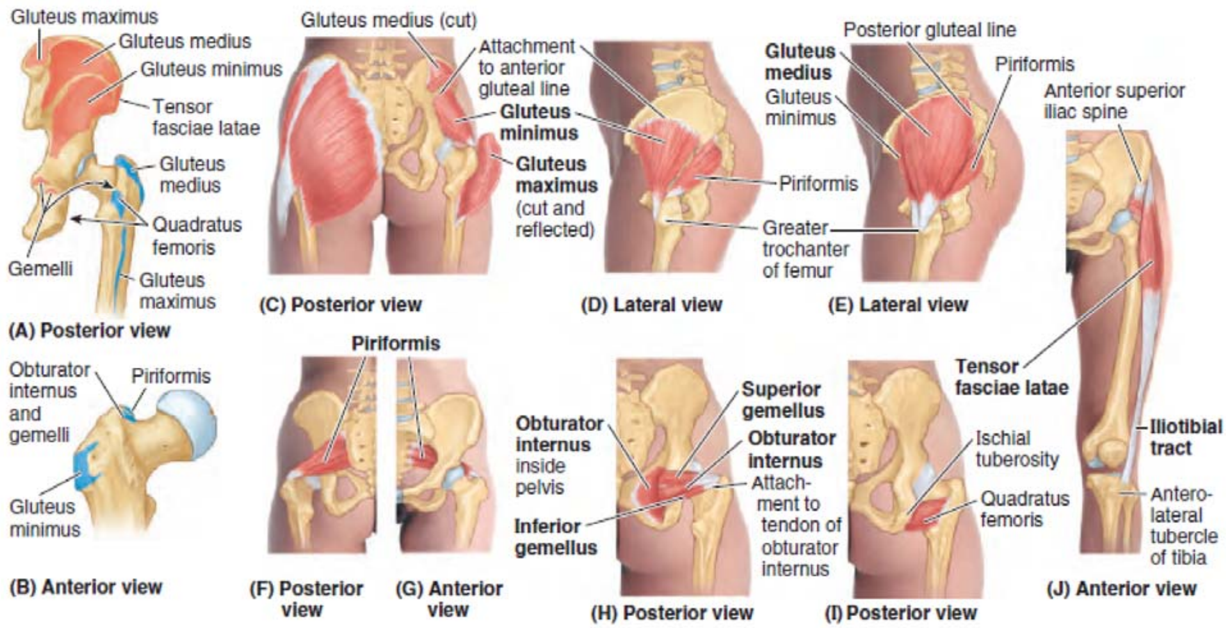

Figure 4: Muscles of the gluteal region. Abductors and lateral rotators (Moore, et al., Clinically Oriented Anatomy, 2014, p. 564).

NERVES OF THE GLUTEAL REGION

The sciatic nerve is the thickest nerve in the body and is approximately 2 cm at its origin. It is considered the nerve of the lower limb since it supplies most muscles and skin of the posterior compartment of the thigh, leg, and foot. It emerges below the piriformis muscle in most cases. However, it is important to highlight that there are several anatomical variations of the sciatic nerve divisions in relation to the piriformis muscle that may play a role in the cause of posterior hip and buttock pain. The branching patterns of the two main divisions of the sciatic nerve, the tibial nerve and the common fibular (common peroneal nerve; external popliteal nerve; lateral popliteal nerve), produce these variations (Natsis, et al., 2014). The sensory and motor components of the nerve are beyond the scope of this paper and will not be discussed.

There are several other nerves that lie within the gluteal region (**Figure 5**). The superior gluteal nerve emerges superior to the piriformis muscle and splits into the superior division that supplies the gluteus medius muscle and the inferior division that supplies the gluteus minimus muscle. Arising from the dorsal divisions of the 5th lumbar and 1st and 2nd sacral ventral rami is the inferior gluteal nerve, which supplies the gluteus maximus muscle. The posterior cutaneous nerve of the thigh is purely sensory and mainly a cutaneous nerve. It arises from the 2nd, 3rd, and 4th sacral ventral rami of the sacral plexus. It supplies the gluteal and perineal region and back of the lower limb. The nerve to obturator internus arises from the ventral divisions of the 5th lumbar ventral rami and the 1st and 2nd sacral ventral rami. It supplies the obturator internus and superior gemellus muscles. The nerve to quadratus femoris arises from the ventral divisions of the 4th and 5th lumbar ventral rami as well as the 1st sacral ventral ramus. It supplies the quadratus femoris and the inferior gemellus muscles. The pudendal nerve arises from the ventral rami of the 2nd, 3rd, and 4th sacral nerves. It exits the pelvis via the greater sciatic foramen and enters the perineum through the lesser sciatic foramen. It supplies perineal structures. The perforating cutaneous nerve arises from the posterior aspect of the 2nd and 3rd sacral ventral rami. It pierces the sacrotuberous ligament and supplies the skin over the inferior and medial part of the buttock (The Royal College of Surgeons of England, 2016).

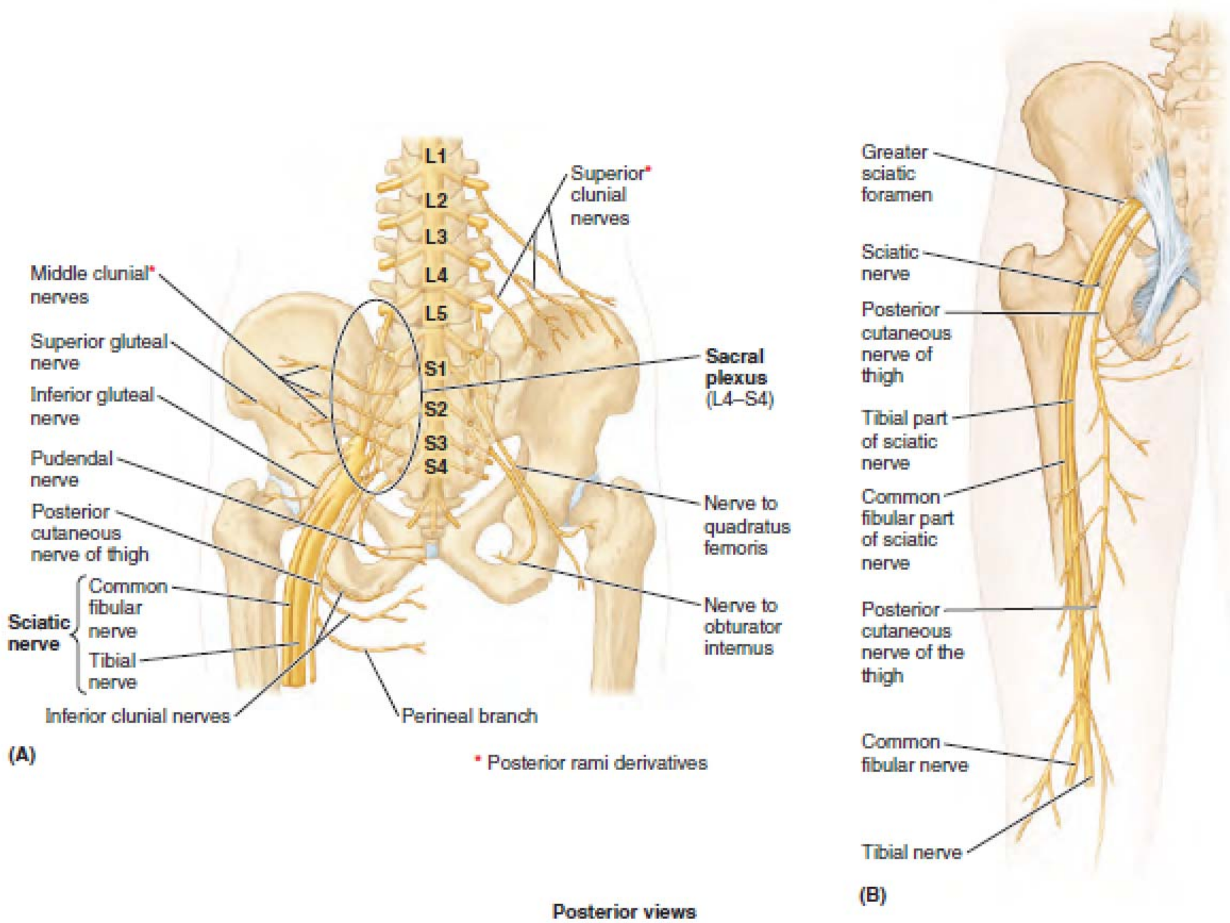

Figure 5: Nerves of the gluteal and posterior thigh regions (Moore, et al., Clinically Oriented Anatomy, 2014, p. 573).

ARTERIES OF THE GLUTEAL REGION

The superior gluteal and inferior gluteal arteries are branches of the internal iliac artery. They supply muscles of the gluteal region and hip joint (**Figure 6**).

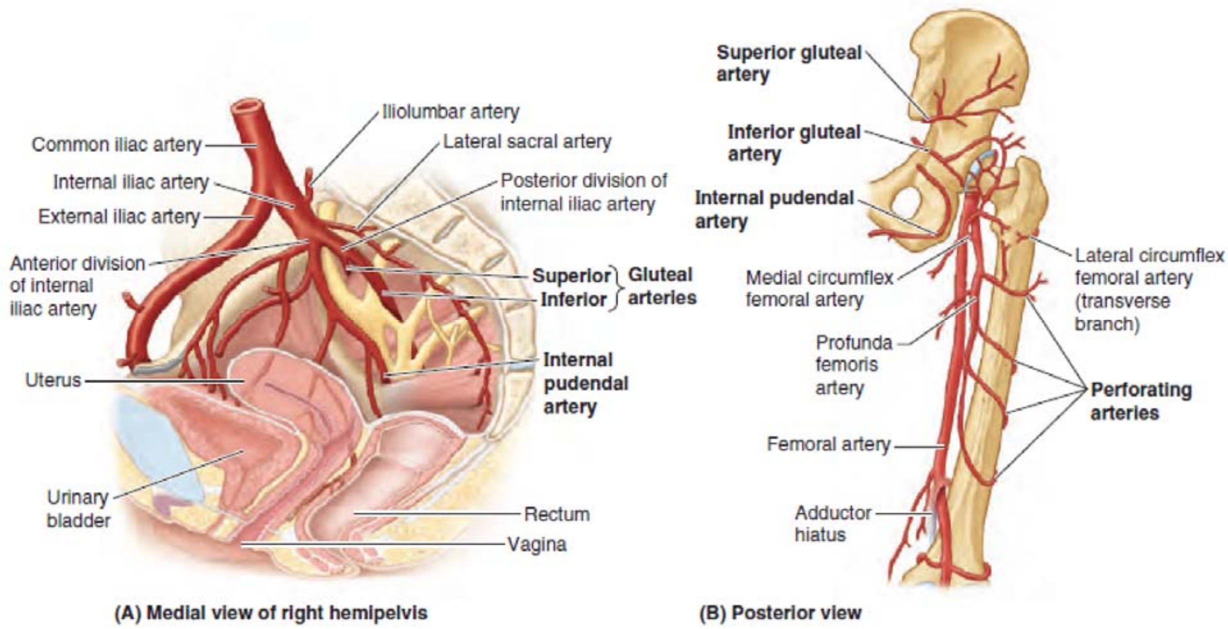

Figure 6: Arteries of the gluteal and posterior thigh regions (Moore, et al., Clinically Oriented Anatomy, 2014, p. 576).

SCIATIC NERVE KINEMATICS WITHIN THE SUBGLUTEAL SPACE

The subgluteal space, also referred to as the deep gluteal space, is the cellular and fatty tissue located between the middle and deep gluteal aponeurosis layers (Martin, et al., 2011). The borders of the subgluteal space are listed in **Table 3**.

Table 3: Subgluteal space borders.

Posteriorly	Gluteus maximus muscle
Anteriorly	Posterior acetabular column, hip joint capsule, and proximal femur Posterior border of the femoral neck
Laterally	Lateral lip of the linea aspera and gluteal tuberosity Linea aspera and the lateral fusion of middle and deep gluteal aponeurosis layers reaching the tensor fasciae latae muscle (iliotibial tract, ITT)
Medially	Sacrotuberous ligament and falciform fascia
Superiorly	Inferior margin of the sciatic notch
Inferiorly	Proximal origin of the hamstrings at ischial tuberosity Hamstring origin

(Martin, et al., 2015)

Sciatic nerve kinematics and possible entrapment of the nerve due to anatomical variations within the subgluteal space is essential to understanding the pathophysiology of posterior hip and buttock pain. The anatomy of the subgluteal space is unique in that the nerve exits the pelvis through the greater sciatic notch and has significant mobility with hip movements as described by Coppieters et al. (2006). They found that the sciatic nerve has 28 mm of excursion during hip flexion. Under normal conditions, the sciatic nerve can stretch and glide to accommodate moderate strain or compression associated with joint movement (Coppieters, et al., 2006). However, this motion is affected by anatomical variances between the sciatic nerve and the piriformis muscle in 16.2% of the population as reported by Smoll et al. (Smoll, 2010). Causes of sciatic nerve entrapment, including anatomical variations, will be discussed in the next section. To date, the kinematics of the sciatic nerve continues to be explored (Carro, et al., 2016). This reiterates the importance of studying the anatomical variations of the sciatic nerve divisions and how entrapment inhibits its mobility which may cause posterior hip and buttock pain.

POSTERIOR HIP AND BUTTOCK PAIN ETIOLOGY

DEEP GLUTEAL SYNDROME

"Deep gluteal syndrome" describes the presence of pain in the buttock and posterior hip region caused from non-discogenic and extrapelvic entrapment of the sciatic nerve. This term has come about through continued research into the anatomy of the subgluteal space. While "piriformis syndrome" has historically been the most common diagnosis of sciatic nerve entrapment within the subgluteal space, research has shown that there may be other structures involved (Kulcu & Naderi, 2008).

There are many known causes of posterior hip and buttock pain, but this research focuses on the ways in which the sciatic nerve could be entrapped, including the role that anatomical variations play. Each entrapment is specific in how it is identified, diagnosed, and treated. Carro et al. provided a comprehensive overview of the etiologies of sciatic nerve entrapments. This included fibrous and fibrovascular bands, piriformis syndrome, gemelli-obturator internus syndrome, quadratus femoris muscle and ischiofemoral pathology, and hamstring conditions (Carro, et al., 2016).

FIBROUS AND FIBROVASCULAR BANDS

There are three types of constricting bands that can limit sciatic nerve mobility: fibrovascular bands, pure fibrous bands, and pure vascular bands. These constricting bands are present in most cases of sciatic nerve entrapment and can cause various symptoms based on their location (**Figure 7**). This type of entrapment is typically found during magnetic resonance neurography (MRN) imaging and endoscopic procedures. Diminished or absent sciatic nerve mobility during hip and knee movements due to these bands is the precipitating cause of sciatic nerve neuropathy (Lewis, et al., 2006).

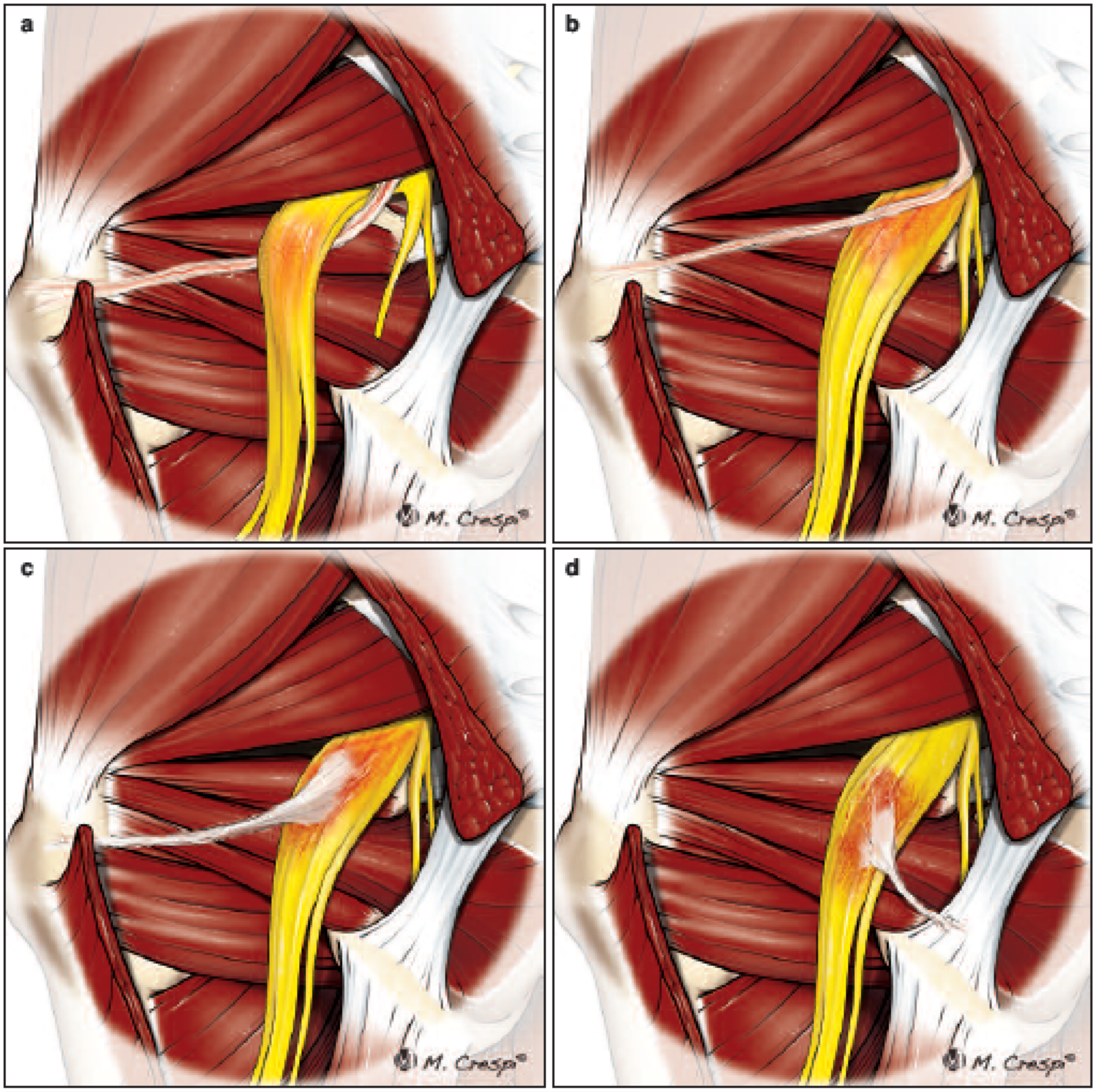

Figure 7 a-d: Pathogenic classification of fibrous/fibrovascular bands. (a, b) Compressive or bridge-type bands limiting the movement of the sciatic nerve from anterior to posterior (type 1A) or from posterior to anterior (type 1B). (c, d) Adhesive or horse-strap bands (type 2), which bind strongly to the sciatic nerve structure, anchoring it in a single direction. They can be attached to the sciatic nerve laterally (type 2A) or medially (type 2B) (Hernando, et al., 2015).

PIRIFORMIS SYNDROME

The diagnosis of piriformis syndrome is often confused with other conditions. While at one point in time piriformis syndrome was a "catch all" diagnosis, new research has suggested that it be considered a subset of deep gluteal syndrome (McCrory & Bell, 1999). This new classification has come about through the identification of the various locations where the sciatic nerve can be entrapped within the subgluteal space. There are three potential sources of pathology related to the piriformis muscle. These include hypertrophy of the piriformis muscle, dynamic sciatic nerve entrapment by the piriformis muscle, and an anomalous course of the sciatic nerve (anatomical variations) (Carro, et al., 2016).

There have been multiple attempts at classifying the various relationships that exist between the sciatic nerve and the piriformis muscle (**Table 4**). One of the earliest known systems of classification was published by Calori in 1881. A series of questions was then released in January of 1895 by Parsons and Keith, who were a part of the Committee of Collective Investigation of the Anatomical Society of Great Britain and Ireland. One question inquired about "the relation of the great sciatic nerve to the piriformis muscle." They received responses from four examiners whose results were divided into three groups: Group A (whole nerve emerging from the pelvis below the piriformis muscle), Group B (the nerve in two trunks, one of which (the common fibular nerve), pierces the piriformis muscle), Group C (whole nerve pierced the piriformis muscle) (Parsons & Keith, 1896). Beaton & Anson utilized this data from Parsons and Keith as the basis of their classification system in 1937. This classification identifies six anatomical variations of the sciatic nerve divisions in relation to the piriformis muscle as shown in **Figure 8**. It is one of the most well-known and utilized classification systems due to the detail that it provides (Beaton & Anson, 1937).

Table 4: Classification Systems: Additional classification systems compared to Beaton & Anson's. The descriptions in the table are the original ones used by Beaton & Anson.

Beaton & Anson (1937)	**Calori (1881)**	**Machado (2003)**	**Shewale (2013)**
1. Undivided nerve below undivided muscle	F1, F7, F8	Normal	E1, E2, E3
2. Divisions of nerve between (common fibular nerve) and below (tibial nerve) undivided muscle	F2, F3	Type I	E4
3. Divisions above (common fibular nerve) and below (tibial nerve) undivided muscle	N/A	Type II	E5
4. Undivided nerve between heads	N/A	Type III	N/A
5. Divisions between (tibial nerve) and above (common fibular nerve) heads (hypothetical)	F4, F5, F6	N/A	N/A
6. Undivided nerve above undivided muscle (hypothetical)	N/A	N/A	N/A

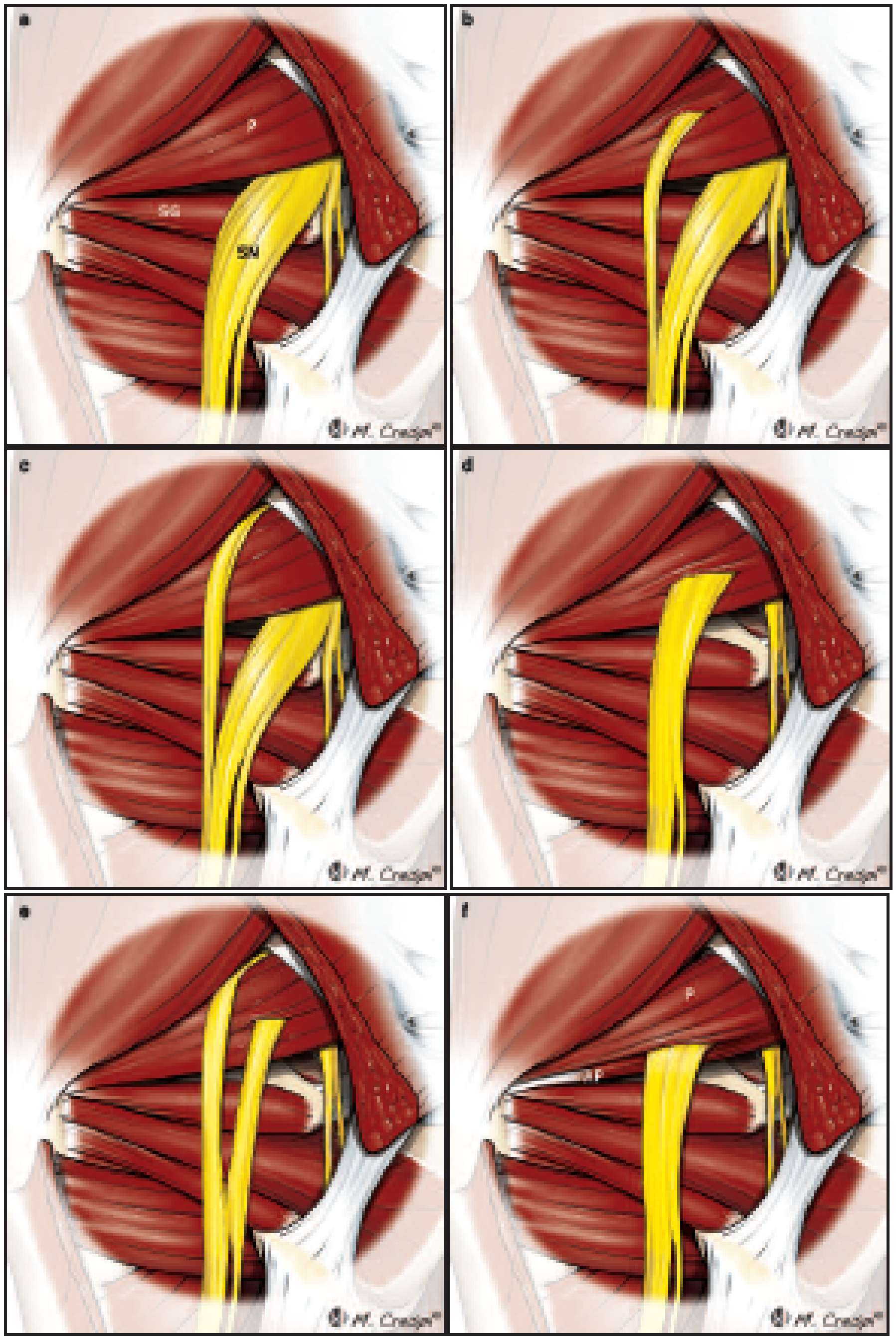

Figure 8 a-f: Anatomic variations of the relationship between the piriformis muscle and sciatic nerve. Diagrams illustrate the six variants, originally described by Beaton and Anson. (a) An undivided nerve comes out below the piriformis muscle (normal course). (b) A divided sciatic nerve passing through and below the piriformis muscle. (c) A divided nerve passing above and below an undivided muscle. (d) An undivided sciatic nerve passing through the piriformis muscle. (e) A divided nerve passing through and above the muscle heads. (f) Diagram showing an unreported additional B-type variation consisting of a smaller accessory piriformis (AP) with its own separate tendon. SN sciatic nerve, P piriformis muscle, SG superior gemellus muscle (Hernando, et al., 2015).

GEMELLI-OBTURATOR INTERNUS SYNDROME

Because of its proximity and similarity in both structure and function, most treatments for piriformis syndrome affect the internal obturator muscle. Obturator internus/gemelli complex pathology is rare, but the dynamic compression of the sciatic nerve caused by a stretched or altered dynamic of the obturator internus muscle should be included as a possible diagnosis for deep gluteal syndrome. As the sciatic nerve passes under the piriformis muscle and over the superior gemellus and obturator internus, a scissor-like effect between the two muscles can be the source of entrapment (Filler & Gilmer-Hill, 2009).

QUADRATUS FEMORIS MUSCLE AND ISCHIOFEMORAL PATHOLOGY

Ischiofemoral impingement (IFI) syndrome is another condition that may cause hip pain and is related to narrowing of the space between the ischial tuberosity and the lesser trochanter of the femur. The clinical assessment of patients with IFI is difficult because the symptoms are imprecise and may be confused with other lumbar and intra or extraarticular hip disease (Hatem, et al., 2015).

HAMSTRING CONDITION

The sciatic nerve can be affected by a wide spectrum of hamstring origin enthesopathies. The most common imaging finding is edema due to sciatic nerve irritation in the acute phase. Chronic inflammatory changes and adhesions cause scar tissue between tendons or muscles and the sciatic nerve which results in entrapment during hip movement (Miller & Webb, 2007).

CONCLUSION

The goal of this project was to identify the anatomical variations of the sciatic nerve divisions in relation to the piriformis muscle and provide awareness of additional sciatic nerve entrapments that are possible within the subgluteal space. While piriformis syndrome was once the "catch-all" diagnosis for posterior hip and buttock pain, there are many potential causes that need to be explored, including sciatic nerve entrapment within the subgluteal space. The purpose of the present study is to expand upon the current data available and create awareness of these other potential anatomical variations of the sciatic nerve divisions with regards to posterior hip and buttock pain etiology. Continued investigation into these etiologies is necessary to diagnose and treat patients. The current means of diagnosis are through physical examination, imaging techniques, and surgery. New methods of diagnosis need to be explored to streamline treatment as the current standards are inefficient and time consuming for physicians and patients. Living in a society where 1.5 billion people experience chronic pain poses a serious threat to our healthcare system, especially surrounding pain management. Research that advances our knowledge base will continue to be instrumental in understanding pain associated with the sciatic nerve and its relation to the piriformis muscle in the subgluteal space.

CHAPTER 2: METHODS

CADAVERIC DONORS

This was a cadaveric study of 120 human lower limbs that comprised of 30 adult males and 30 adult females from the gross anatomy lab of the department of Genetics, Cell Biology, and Anatomy at The University of Nebraska Medical Center. The donors ranged in age from 44 to 100 years old with the average being 80.3 years old. These cadavers met criteria for UNMC's Deeded Body Program as established by the Anatomical Board of the State of Nebraska (Deeded Body Program, n.d.). This Board is the agency with legal responsibility for the care and assignment of donors for scientific studies within medical and dental centers in Nebraska. The Board distributes the donors among the educational institutions as needed in order to make optimum use of all donors. Studies of anatomical donors are for educational and research purposes only. Generally, most studies are concluded within two years. Upon completion of the study, a reasonable attempt is made to notify the donor's family. Cremated remains of a donor not claimed within one year following the notification, or the attempted notification, of the donor's family will be interred or entombed in a common plot owned by the designated university in an Omaha cemetery.

Donors must fill out and return a Certificate of Bequeathal to the Board for acceptance before the enrollment is complete. There are several pages of instructions that accompany this form and provide detailed information on the body donation program. One component of the form is a page regarding the donor's medical history. This is to be filled out and returned by the donor. Information requested includes height, weight, disease history, operation and accident history, and any disabilities or deformities. Bodies may not be accepted if any of the following conditions are present: autopsy, organs or parts removed for transplantation (with the exception of eyes), decomposition of the body, severe trauma, drowning, burning, homicide, motor-vehicle accident, death from suicide, contagious disease such as HIV or Hepatitis B or C, morbid obesity, emaciation, body contracture, jaundice, edema or a body mass index less than 19 or greater than 30. The Board cannot receive donors when storage is full. Additionally, there are instructions for survivors of potential donors which should be given to a family member, close friend, or an attorney. A copy of the Bequeathal Form is located in **Appendix B**.

DISSECTION AND DATA COLLECTION PROCEDURE

In an effort to maximize the anatomical donations and obtain as much information as possible from these donors, dissections of the gluteal region and posterior thigh were used. These dissections were initiated by first-year medical students and students in the physician assistant, physical therapy, and masters of medical anatomy programs. Following procedures listed in the Interactive Dissection Guide provided by UNMC (**Appendix A**), the students began by sufficiently removing the fascia from the surfaces of the gluteus maximus muscle in the gluteal region bilaterally to ascertain the borders and attachments of this major muscular structure. The students then bisected this muscle into two equal halves with a vertical cut that was slightly lateral to the posterior femoral cutaneous nerve. They reflected the cut muscle medially and laterally and were careful not to remove the sacrotuberous ligament to which the gluteus maximus is attached when reflecting the medial half of the muscle. After reflection of the gluteus maximus medially and laterally, the piriformis muscle and sciatic nerve were located (Todd, et al., 2016). The present study identified the sciatic nerve and any variations of its divisions in relation to the piriformis muscle. The data collected was classified into one of the six possible variations that have been identified by researchers. Minimal additional dissections were required for the present study to fully observe the divisions of the sciatic nerve. High-resolution images were taken using a Canon EOS Rebel T5 digital camera to keep a visual record of the data collected. The data was collected by hand and then transferred to a Microsoft Excel spreadsheet so that the information could be organized by age, race, gender, and variation.

STATISTICS

Comparisons between the present study and the primary literature were done using the chi-square test. The results are presented in Chapter 3. The "Chi-Square Calculator for 2 x 2 Contingency Table" on the Social Science Statistics website was used to perform each of the chi-square tests (Chi-Square Calculator, 2017). The first step was to fill in the group (column) and category (row) information for the contingency table. After entering group and category names, the appropriate values were entered into cells within the contingency table and a significance level of .05 was selected. The calculation was performed and the website provided the contingency table with observed cell totals, the expected cell totals, and the chi-square statistic for each cell. It also provided a chi-square statistic, p-value, and statement of significance beneath the table. Blue text designates that the result was significant and red text designates that the result was not significant. Lower p-values indicate a more statistically significant result, that is, a result that is less likely to be the result of random chance alone.

CHAPTER 3: RESULTS

The data collected during the present study regarding the anatomical variations of the sciatic nerve divisions in relation to the piriformis muscle will be presented in this chapter. This data will be compared to the primary literature values compiled from 24 adult cadaveric studies. The data from the present study and adult cadaveric studies will be compared to the primary literature values compiled from four fetal cadaveric studies and seven live surgical studies. A comparison between nationalities will also be reviewed. The clinical implications of the results presented in this chapter will be discussed in Chapter 4.

The relationship between the piriformis muscle and the sciatic nerve and its divisions were classified using Beaton and Anson using a six-category classification system. This system was used for the classification of the present study because it is most commonly used throughout the primary literature. The lumbosacral plexus is formed on the ventral side of the piriformis muscle and the sciatic nerve exits deep and inferior to the piriformis muscle (Dudek, 2014). This is what Beaton and Anson identified as type “A,” or normal, due to the percentages of this type being significantly greater when they first examined 120 cadavers between 1937 and 1938. Compiled data from the primary literature of adult cadaveric studies included Beaton and Anson’s data along with several other studies ranging from 1896 to 2016. This data compilation shows that 5,250 out of 6,316 (83.1%) human lower limbs had this type “A” variation (**Table 5**). The present study found that 117 out of 120 (97.5%) human lower limbs had this type “A” variation as well (**Table 5**). An example of this type “A” variation found during the present study can be seen in **Figure 9**. While type “A” is categorically a variation, these large percentages in both the data from the primary literature and the present study agree with Beaton and Anson’s findings of normal and will no longer be considered a variation for the purpose of the present study. Variations different than normal type “A” have been classified as types “B” through “F.” The present study only found the type “B” variation (**Figure 10**) in three limbs while the adult cadaveric studies from the primary literature found the following variations: 857 type “B,” 88 type “C,” 36 type “D,” 5 type “E,” and

5 type “F” (**Table 5**). Normal, non-variant, type “A” was compared to types “B” through “F,” variant, in analyzing the results.

Table 5: Normal and anomalous limb percentages for the present study and for adult cadaveric studies (primary literature).

Investigator	A	B	C	D	E	F	Total limbs	Total Limbs with Variations B-F	Normal (Type A)
Adult Cadaveric Studies (Primary Literature), 1896-2016	5250	857	88	36	5	5	6316	1066 (16.9%)	5250 (83.1%)
Present Study, 2017	117	3	0	0	0	0	120	3 (2.5%)	117 (97.5%)

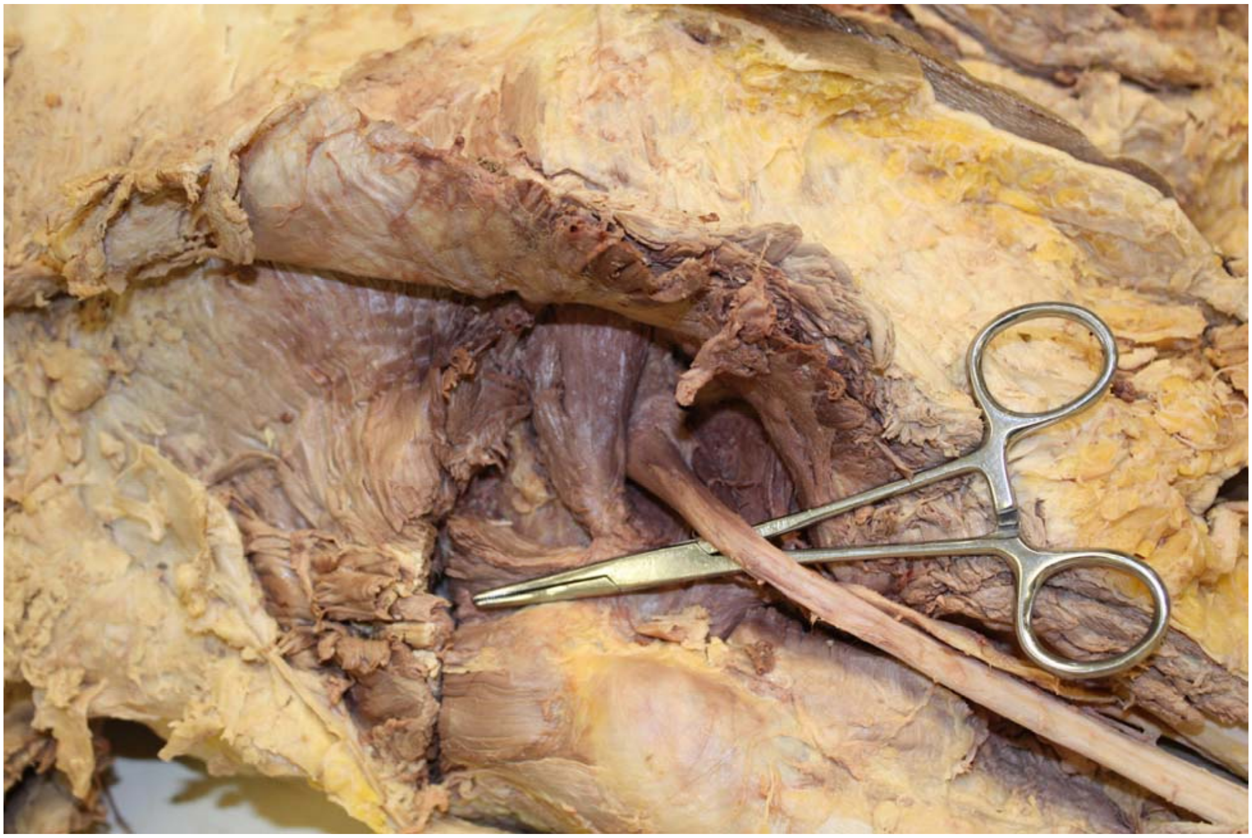

Figure 9: Undivided sciatic nerve below undivided piriformis muscle. This image was obtained during the present study.

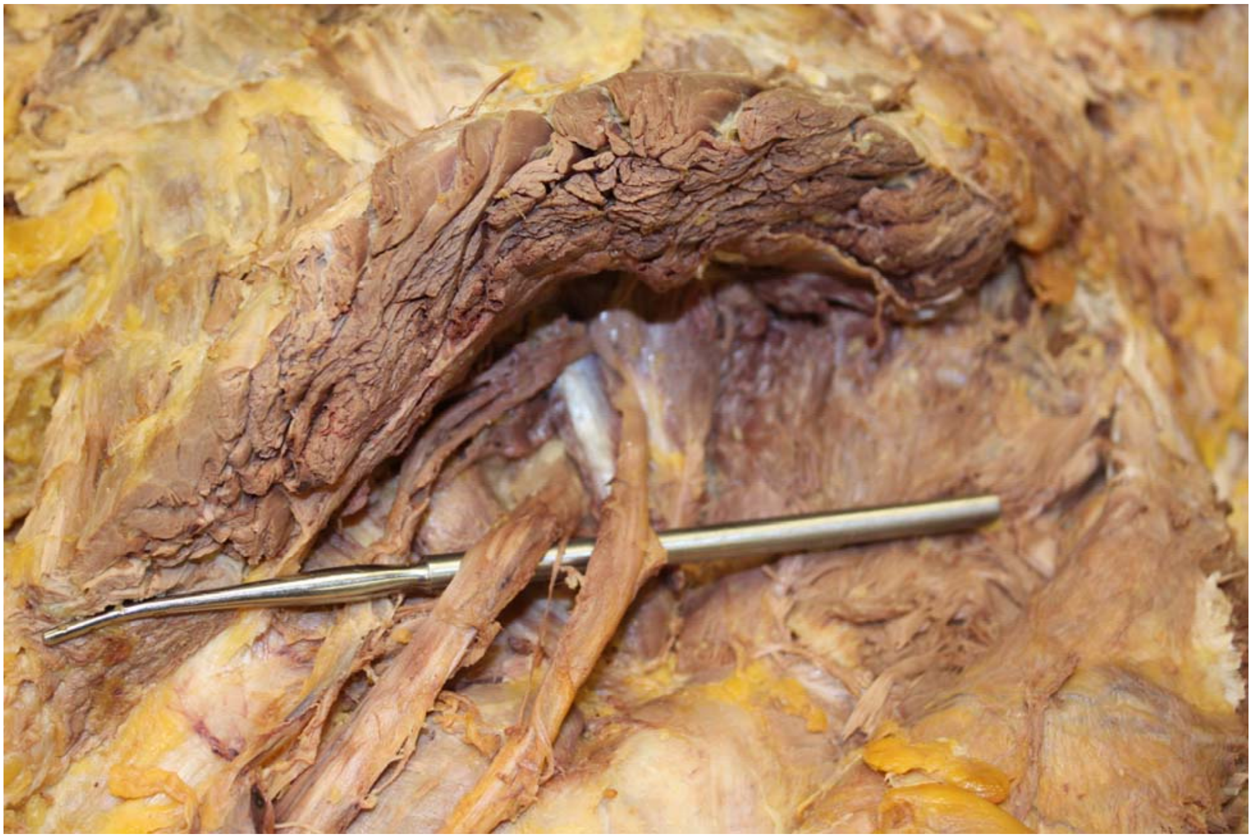

Figure 10: Divisions of the sciatic nerve between (common peroneal nerve) and below (tibial nerve) the piriformis muscle. This image was obtained during the present study.

ADULT CADAVERIC STUDIES (PRIMARY LITERATURE)

The data from the primary literature consisted of 24 adult cadaveric studies published between the years 1896 and 2016. Each study compared their observations to Beaton and Anson's classification system and reported variation results accordingly. To facilitate the analysis of the prevalence of anatomical variations of the sciatic nerve divisions in relation to the piriformis muscle, variation types "B" through "F" were added together. This sum of types "B" through "F" was then divided by the total number of limbs and multiplied by 100 to produce a percentage of anomalous limbs. Type "B" was found in 857 out of 6,316 (13.6%) limbs and is the most common variation in the adult cadaveric studies examined as defined by the present study. Of these 6,316 limbs, type "C" was found in 88 (1.4%), type "D" was found in 36 (0.6%), and type "E" and "F" were each found in 5 (0.08%). Since types "B" through "F" represent the anomalies that are present, they were grouped together when analyzing the data. All observations were extracted and compiled into (**Table 6**).

Table 6: Primary literature values for adult cadaveric studies. Trotter (1932) and Fishman, et al. (2002) Studies highlighted in yellow did not report the number of anomalies separately, but as the total number of limbs with variations B-F.

Investigator	A	B	C	D	E	F	Total limbs	Total limbs with variations B-F	Nationality
Parsons & Keith, 1896	118	17	0	3	0	0	138	20 (14.5%)	English
Bardeen, 1901	220	25	1	0	0	0	246	26 (10.6%)	American
Trotter, 1932	400	-	-	-	-	-	464	64 (13.8%)	American (Whites and African Americans)
Ming-Tzu, 1941	92	46	0	2	0	0	140	48 (34.3%)	Chinese
Misra, 1954	262	18	12	8	0	0	300	38 (12.7%)	Indian
Anson & McVay, 1971	1789	201	13	5	0	0	2008	219 (10.9%)	American (Whites and African Americans)
Nizankowski, 1972	181	8	3	5	3	0	200	19 (9.5%)	Polish
Lee & Tsai, 1974	118	33	7	3	2	5	168	50 (29.8%)	Chinese
Pecina, 1979	102	27	1	0	0	0	130	28 (21.5%)	Yugoslavian
Chiba, 1992	328	173	10	0	0	0	511	183 (35.8%)	Japanese
Chiba, et al., 1994	285	148	9	0	0	0	442	157 (35.5%)	Japanese
Pokorny, et al., 1998	82	14	4	2	0	0	102	20 (19.6%)	Czech
Fishman, et al., 2002	65	-	-	-	-	-	76	11 (14.5%)	American
Benzon, et al., 2003	65	1	0	0	0	0	66	1 (1.5%)	American
Agur & Dalley, 2005	557	79	3	0	0	0	639	82 (12.8%)	N/A
Pokorny, et al., 2006	144	26	8	4	0	0	182	38 (20.9%)	Czech
Guvencer, et al., 2009	38	8	4	0	0	0	50	12 (24.0%)	Turkish
Patel, et al., 2011	79	2	5	0	0	0	86	7 (8.1%)	Indian
Brooks, et al., 2011	36	0	0	4	0	0	40	4 (10.0%)	Brazilian
Shewale, et al., 2013	78	10	2	0	0	0	90	12 (13.3%)	Indian
Adibatti, et al., 2014	48	1	1	0	0	0	50	2 (4.0%)	Indian
Haladaj, et al., 2015	23	6	1	0	0	0	30	7 (23.3%)	Polish
Berihu, et al., 2015	50	5	1	0	0	0	56	6 (10.7%)	Ethiopian
Lewis, et al., 2016	90	9	3	0	0	0	102	12 (11.8%)	American
Total	**5250**	**857**	**88**	**36**	**5**	**5**	**6316**	**1066 (16.9%)**	

NATIONALITY AND REGIONAL COMPARISONS

Nationalities of the cadavers for all 24 adult cadaveric studies published between the years 1896 and 2016 were extracted. The nationalities were assigned to their respective countries and NationsOnline.org was used to identify the corresponding region of each country (Nations Online, 2017). If more than one country existed within the same region, as determined by the website, the data was combined. Variation types "B" through "F" were added together and this sum was then divided by the total number of limbs and multiplied by 100 to produce a percentage of anomalous limbs for each region. This data is shown in **Table 7**.

Table 7: Regional Comparison of Adult Cadaveric Studies (Primary Literature). The present study involved cadavers from the United States and is included in the table below.

<table>
<tr><th>Continent</th><th>Region</th><th>Country</th><th>Total Limbs</th><th>Type A</th><th>Types B-F</th><th>Percent Anomalous</th></tr>
<tr><td>Africa</td><td>Eastern Africa</td><td>Ethiopia</td><td>56</td><td>50</td><td>6</td><td>10.7</td></tr>
<tr><td rowspan="4">Europe</td><td>Northern Europe</td><td>England</td><td>138</td><td>118</td><td>20</td><td>14.5</td></tr>
<tr><td>Southern Europe</td><td>Yugoslavia</td><td>130</td><td>102</td><td>28</td><td>21.5</td></tr>
<tr><td rowspan="2">Eastern Europe</td><td>Poland</td><td rowspan="2">514</td><td rowspan="2">430</td><td rowspan="2">84</td><td rowspan="2">16.3</td></tr>
<tr><td>Czech Republic</td></tr>
<tr><td rowspan="4">Asia</td><td>South Central Asia</td><td>India</td><td>526</td><td>467</td><td>59</td><td>11.2</td></tr>
<tr><td rowspan="2">Eastern Asia</td><td>China</td><td rowspan="2">1261</td><td rowspan="2">823</td><td rowspan="2">438</td><td rowspan="2">34.7</td></tr>
<tr><td>Japan</td></tr>
<tr><td>Western Asian and the Middle East</td><td>Turkey</td><td>50</td><td>38</td><td>12</td><td>24.0</td></tr>
<tr><td>South America</td><td>-</td><td>Brazil</td><td>40</td><td>36</td><td>4</td><td>10.0</td></tr>
<tr><td>North America</td><td>-</td><td>United States</td><td>3082</td><td>2746</td><td>336</td><td>10.9</td></tr>
</table>

One observation made by the present study is the higher percentage (34.7%) of anomalous lower limbs present in the Eastern Asian region. This region includes China and Japan. It is unknown if people from this region experience higher rates of posterior hip and buttock pain. There may be higher incidences of these anatomical variations that could cause piriformis syndrome, but more research needs to be done to further investigate.

To determine if the Eastern Asian data should be included with the other regions examined, a chi-square test was performed. This chi-square test compared normal values versus variation types “B” through “F” values for adult cadaveric studies from Eastern Asia and adult cadaveric studies of other regions. The results of this chi-square test are shown in **Table 8**.

Table 8: Eastern Asia (Adult Cadaveric Studies) vs. Other Regions Examined (Adult Cadaveric Studies)

	No Variation (Type A)	**Variation (Types B-F)**	***Marginal Row Totals***
Eastern Asia (Adult Cadaveric Studies)	1261 (1451.81) [25.08]	438 (247.19) [147.3]	1699
Other Regions Examined (Adult Cadaveric Studies)	4536 (4345.19) [8.38]	549 (739.81) [49.21]	5085
Marginal Column Totals	5795	987	6784 (Grand Total)
The chi-square statistic is 229.9699. The p-value is <0.0001. This result is significant at p < .05.			

The chi-square statistic is 229.9699. The website did not provide a specific p-value, but stated that it was less than 0.0001 and that the result was significant. The p-value is extremely small which suggests that the data from Eastern Asia and the data from the other regions are significantly different. Because the result is significantly different, the present study excluded Eastern Asia from future comparisons. Additionally, the primary literature data of the fetal cadaveric and surgical studies did not need to be modified because these studies were not performed in the Eastern Asian region.

FETAL CADAVERIC STUDIES (PRIMARY LITERATURE)

Fetal studies considered in the present study consisted of fetuses that ranged in age from 9 to 37 weeks. The data from the primary literature consisted of four fetal cadaveric studies published between the years 1999 and 2014. The cause of death of these fetuses was not provided. Each study reported the variations that they observed according to Beaton and Anson's classification system. To facilitate the analysis of the prevalence of anatomical variations of the sciatic nerve divisions in relation to the piriformis muscle, variation types "B" through "F" were added together. This sum of types "B" through "F" was then divided by the total number of limbs and multiplied by 100 to produce a percentage of anomalous fetal lower limbs. Type "B" was found in 38 out of 450 (8.4%) fetal limbs and is the most common variation in the fetal cadaveric studies examined as defined by the present study. Of these 450 fetal lower limbs, type "C" was found in 8 (1.8%), and type "D" was found in 10 (2.2%). Types "E" and "F" were not found. Since types "B" through "F" represent the anomalies that are present, they were grouped together when analyzing the data. All observations were extracted and compiled into **Table 9**.

Table 9: Primary literature values for fetal cadaveric studies.

Investigator	A	B	C	D	E	F	Total limbs	Total limbs with variations B-F	Nationality
Uluutku & Kurtoğlu, 1999	37	8	0	5	0	0	50	13 (26.0%)	Turkish
Machado, et al., 2003	80	16	2	2	0	0	100	20 (20.0%)	Brazilian
Ugrenovic, et al., 2005	192	5	3	0	0	0	200	8 (4.0%)	Serbian
Sinha, et al., 2014	85	9	3	3	0	0	100	15 (15.0%)	Indian
Total	**394**	**38**	**8**	**10**	**0**	**0**	**450**	**56 (12.4%)**	

The second chi-square test performed was to compare normal values versus variation types "B" through "F" values for fetal cadaveric studies and adult cadaveric studies. The results of this chi-square test are shown in **Table 10**.

Table 10: Fetal Cadaveric Studies (Primary Literature) vs. Adult Cadaveric Studies (Eastern Asia Excluded)

	No Variation (Type A)	**Variation (Types B-F)**	***Marginal Row Totals***
Fetal Cadaveric Studies (Primary Literature)	394 (395.4) [0]	56 (54.6) [0.04]	450
Adult Cadaveric Studies (Eastern Asia Excluded)	3987 (3985.6) [0]	549 (550.4) [0]	4536
Marginal Column Totals	4381	605	4986 (Grand Total)
The chi-square statistic is 0.0447. The p-value is .832519. This result is not significant at p < .05.			

The chi-square statistic is 0.0447 and the p-value is .832519 which indicates that the result is not significant. This suggests that the data from fetal cadaveric studies and the data from adult cadaveric studies are not significantly different.

Between weeks four and six of embryological development, at the base of the limb bud, local cell biological messages are produced which guide the early nerve fibers into the limb bud (Dudek, 2014). These nerves to the lower limb form two plexuses, lumbar and sacral. Later, as the elements from each of these plexuses grow out into the limb, they get sub-divided into dorsal and ventral components for the dorsal and ventral musculature. The sciatic nerve is formed when the large dorsal component of the sacral plexus (common peroneal nerve) and ventral component (tibial nerve) move downwards close together (Dudek, 2014). Depending upon the development, it is possible that the common peroneal and the tibial nerves separate from each other at different levels from their origins. This may also occur between weeks four and six of embryological development. The end of the eighth week signifies the end of the embryonic period and the beginning of the fetal period. At this time, the primordia of all major adult organs and structures are present (Dudek, 2014).

SURGICAL STUDIES

The present study examined seven surgical studies compiled by Smoll that were published between the years 1999 to 2008. Smoll was looking to determine the prevalence of anomalies found in patients undergoing surgery for piriformis syndrome. The number of surgeries performed and number of anomalies reported were extracted from each study. Using this data, percentages of the anomalies for each study were calculated. All observations were compiled into **Table 11**.

Table 11: Prevalence of piriformis and sciatic nerve division variations in published surgical studies for piriformis syndrome.

Investigator	Number of surgeries performed	Number of anomalies reported	Nationality
Benson & Schutzer, 1999	15	1 (6.7%)	American
Fishman, et al., 2002	43	6 (14.0%)	American
Indrekvam & Sudmann, 2002	19	4 (21.1%)	Norwegian
Foster, 2002	7	0 (0.0%)	American
Meknas, et al., 2003	6	0 (0.0%)	Norwegian
Chin, et al., 2005	30	7 (23.3%)	American
Pecina, et al., 2008	10	3 (30.0%)	Yugoslavian
Total	**130**	**21 (16.2%)**	

Anatomical variations of the sciatic nerve divisions in relation to the piriformis muscle may lead to piriformis syndrome which is a subset of deep gluteal syndrome. A third chi-square test was performed to understand if those patients undergoing surgical treatment for piriformis syndrome were more likely to have one of these anomalies. The results of this chi-square test are shown in **Table 12**.

Table 12: Surgical Studies vs. Adult Cadaveric Studies (Eastern Asia Excluded)

	No Variation (Type A)	**Variation (Types B-F)**	***Marginal Row Totals***
Surgical Studies	109 (114.12) [0.23]	21 (15.88) [1.65]	130
Adult Cadaveric Studies (Eastern Asia Excluded)	3987 (3981.88) [0.01]	549 (554.12) [0.05]	4536
Marginal Column Totals	4096	570	4666 (Grand Total)
The chi-square statistic is 1.9337. The p-value is .164358. This result is not significant at p < .05.			

The chi-square statistic is 1.9337 and the p-value is .164358 which indicates that the result is not significant. This suggests that the data from surgical studies and the data from adult cadaveric studies are not significantly different.

One reported cause of piriformis syndrome is anatomical variations of the sciatic nerve divisions in relation to the piriformis muscle. The result from the chi-square test in **Table 12** suggests that patients diagnosed with piriformis syndrome appear just as likely as the general population to have a piriformis and sciatic nerve anomaly. This could be due to the small sample size of the surgical patients or even the misdiagnosis of piriformis syndrome within the surgical patients. The clinical implications of this analysis will be reviewed in Chapter 4.

PRESENT STUDY

The fourth chi-square test performed was to compare normal values versus variation types “B” through “F” values for the present study and adult cadaveric studies. The results of this chi-square test are shown in **Table 13**.

Table 13: Present Study vs. Adult Cadaveric Studies (Eastern Asia Excluded)

	No Variation (Type A)	**Variation (Types B-F)**	***Marginal Row Totals***
Present Study	117 (105.77) [1.19]	3 (14.23) [8.86]	120
Adult Cadaveric Studies (Eastern Asia Excluded)	3987 (3998.23) [0.03]	549 (537.77) [0.23]	4536
Marginal Column Totals	4104	552	4656 (Grand Total)
The chi-square statistic is 10.3169. The p-value is .001318. This result is significant at $p < .05$.			

The chi-square statistic is 10.3169 and the p-value is .001318 which indicates that the result is significant. This suggests that the data from the present study and the data from adult cadaveric studies are significantly different.

The fifth chi-square test performed was to compare normal values versus variation types "B" through "F" values for the present study and American adult cadaveric studies. The results of this chi-square test are shown in **Table 14**.

Table 14: Present Study vs. Adult Cadaveric Studies (American)

	No Variation (Type A)	**Variation (Types B-F)**	***Marginal Row Totals***
Present Study	117 (107.3) [0.88]	3 (12.7) [7.41]	120
Adult Cadaveric Studies (American)	2746 (2755.7) [0.03]	336 (326.3) [0.29]	3082
Marginal Column Totals	2863	339	3202 (Grand Total)
The chi-square statistic is 8.6135. The p-value is .003337. This result is significant at $p < .05$.			

The chi-square statistic is 8.6135 and the p-value is .003337 which indicates that the result is significant. This suggests that the data from the present study and the data from American adult cadaveric studies are significantly different.

The sixth chi-square test performed was to compare normal values versus variation types “B” through “F” values for the present study and European adult cadaveric studies. The results of this chi-square test are shown in **Table 15**.

Table 15: Present Study vs. Adult Cadaveric Studies (European)

	No Variation (Type A)	**Variation (Types B-F)**	***Marginal Row Totals***
Present Study	117 (102.04) [2.19]	3 (17.96) [12.46]	120
Adult Cadaveric Studies (European)	650 (664.96) [0.34]	132 (117.04) [1.91]	782
Marginal Column Totals	767	135	902 (Grand Total)
The chi-square statistic is 16.9033. The p-value is .000039. This result is significant at $p < .05$.			

The chi-square statistic is 16.9033 and the p-value is .000039 which indicates that the result is significant. This suggests that the data from the present study and the data from European adult cadaveric studies are significantly different.

The seventh chi-square test performed was to compare normal values versus variation types “B” through “F” values for the present study and fetal cadaveric studies. The results of this chi-square test are shown in **Table 16**.

Table 16: Present Study vs. Fetal Cadaveric Studies (Primary Literature)

	No Variation (Type A)	**Variation (Types B-F)**	***Marginal Row Totals***
Present Study	117 (107.58) [0.83]	3 (12.42) [7.15]	120
Fetal Cadaveric Studies (Primary Literature)	394 (403.42) [0.22]	56 (46.58) [1.91]	450
Marginal Column Totals	511	59	570 (Grand Total)
The chi-square statistic is 10.0962. The p-value is .001486. This result is significant at $p < .05$.			

The chi-square statistic is 10.0962 and the p-value is .001486 which indicates that the result is significant. This suggests that the data from the present study and the data from fetal cadaveric studies are significantly different.

The eighth chi-square test performed was to compare normal values versus variation types “B” through “F” values for the present study and surgical studies. The results of this chi-square test are shown in **Table 17**.

Table 17: Present Study vs. Surgical Studies

	No Variation (Type A)	**Variation (Types B-F)**	***Marginal Row Totals***
Present Study	117 (108.48) [0.67]	3 (11.52) [6.3]	120
Surgical Studies	109 (117.52) [0.62]	21 (12.48) [5.82]	130
Marginal Column Totals	226	24	250 (Grand Total)
The chi-square statistic is 13.4046. The p-value is .000251. This result is significant at $p < .05$.			

The chi-square statistic is 13.4046 and the p-value is .000251 which indicates that the result is significant. This suggests that the data from the present study and the data from surgical studies are significantly different.

CHAPTER 4: DISCUSSION

The goal of this project was to identify and quantify the anatomical variations of the sciatic nerve divisions in relation to the piriformis muscle and compare the data collected to the primary literature. This was done in an effort to provide awareness of sciatic nerve entrapments within the subgluteal space that may be responsible for posterior hip and buttock pain. While the current means of diagnosis are through physical examination, imaging techniques, and surgery, the results of this present study indicate that new methods of diagnosis need to be explored.

The present cadaveric study of 120 human lower limbs was comprised of 30 adult males and 30 adult females from the gross anatomy lab of the department of Genetics, Cell Biology, and Anatomy at The University of Nebraska Medical Center. The data collected was compared to the primary literature which consisted of compiled data from several adult cadaveric studies, fetal cadaveric studies, and surgical studies. These comparisons were made due to clinical implications that may result from anatomical variations.

"Deep gluteal syndrome" describes the presence of pain in the buttock and posterior hip region caused from non-discogenic and extrapelvic entrapment of the sciatic nerve (Kulcu & Naderi, 2008). The present study aims to provide additional information to support the use of deep gluteal syndrome versus the historically common and potentially inaccurate diagnosis of piriformis syndrome. Carro et al. provided a comprehensive overview of the etiologies of sciatic nerve entrapments. This included fibrous and fibrovascular bands, piriformis syndrome, gemelli-obturator internus syndrome, quadratus femoris muscle and ischiofemoral pathology, and hamstring conditions (Carro, et al., 2016). While all of these entrapments may be potential causes of posterior hip and buttock pain, the present study focused exclusively on piriformis syndrome and the role that anatomical variations play. Analyzing entrapments unrelated to piriformis syndrome was ruled out due to the complexity of identifying them in cadavers. Identification of these additional entrapments can only be made through experienced dissections in cadavers or via endoscopic investigation. This illustrates a limitation of the broader collection of data regarding deep gluteal syndrome.

LIMITATIONS

IMAGING

One consideration that was made during the present study was the investigation of the use of imaging for diagnosing patients with posterior hip and buttock pain. Imaging techniques such as ultrasound and magnetic resonance imaging (MRI) are limited in the amount of information that they can provide about peripheral nerves. However, magnetic resonance neurography (MRN), which is the direct imaging of nerves in the body by optimizing selectivity for unique MRI water properties of nerves, can be used to provide a detailed image of the compression of the sciatic nerve (Lewis, et al., 2006). There are no known published studies at this time that specifically focus on the utilization of MRN to examine cases of sciatica that may be caused by anatomical variations of the sciatic nerve divisions in relation to the piriformis muscle. As this imaging technique continues to grow and become more popular, researchers and physicians will be able to more accurately identify, diagnose, and treat pain associated with compression/entrapment of the sciatic nerve. Due to the lack of studies regarding this type of imaging, it was not examined in the present study.

STUDENT DISSECTIONS

Due to the complexity of the gluteal region, there were several limitations that restricted the data that could be obtained during the present study. Student dissections were unreliable when it came to recording the length, width, and origin of its divisions. This was one of the most challenging aspects involved with the present study. Students may have pulled the nerves apart during dissection and for this reason, the present study did not record this information. The lack of experience of the students performing the dissections inhibited the present study from analyzing other causes of deep gluteal syndrome. In cadaveric studies, these other entrapments may only be found through detailed and experienced dissections.

MEDICAL HISTORY

Another limitation of the present study involved the lack of information regarding the medical history of the donors. This data was not available; therefore, the present study was unable to identify whether the donors were diagnosed with piriformis syndrome, experienced trauma to the region, or had posterior hip and buttock pain. This history is required to make comparisons between whether an anatomical variation was responsible for pain. Due to this lack of information, the present study looked at published surgical studies that contained patients with clinically diagnosed piriformis syndrome and compared analyzed the percentage of these patients that had an anatomical variation.

PREVALENCE AND LATERALITY OF VARIATIONS BASED ON SEX

The present study recorded the sex of each cadaver along with the variation found on each side. Analyzing the relation between sex and prevalence of laterality of variations was not possible given that the primary literature data did not always include this level of detail. Future research regarding anatomical variations should establish guidelines to ensure collection of this data in an efficient manner so that it may be analyzed in future research.

The present study focused on identifying the source of posterior hip and buttock pain. With this goal in mind, the anatomical variations of the sciatic nerve divisions in relation to the piriformis muscle were examined. These anatomical variations were chosen because they may have the most implications in this chronic pain.

NATIONALITY AND REGIONAL COMPARISONS OF ADULT CADAVERIC STUDIES (PRIMARY LITERATURE)

The present study observed a higher percentage (34.7%) of anomalous lower limbs present in cadavers from the Eastern Asian region. When comparing this data versus the data from other regions of the world, the present study found that the data was significantly different. Due to this difference, the Eastern Asian data was excluded from future comparisons. Assuming cadavers are valid representations of the normal living population within that region, one could theorize that patients from this region may have a higher prevalence of posterior hip and buttock pain. However, the present study was not able to make this connection as the medical history of these donors was unknown. Future studies related to this topic are recommended to investigate the relationship between nationality and the prevalence of anatomical variations and should ensure that a complete medical history of the donors is available in addition to the previously mentioned lifestyle factors. Additionally, healthcare systems amongst regions of the world are not standardized thus the reporting of pain is extremely varied and may not be indicative of the “true” daily manifestation of pain in individuals. This should be taken into consideration in future studies.

FETAL CADAVERIC STUDIES (PRIMARY LITERATURE)

The result of the comparison made between adult cadaveric studies and fetal cadaveric studies did not show a significant difference in the data. This suggests that fetal cadavers appear just as likely as adult cadavers to have a piriformis muscle and sciatic nerve anomaly. By the end of the eighth week of gestation, the primordia of all major adult organs and structures should be present (Dudek, 2014). This may explain the data that suggests that age does not have an impact on the presence of an anomaly. The results of the present study may have been affected by low sample size, therefore, future studies may want to increase their sample sizes to ensure the accuracy of these findings.

SURGICAL STUDIES

When comparing the data of the adult cadaveric studies to the data of surgical studies there was no significant difference as signified by the p-value .164358. This result from Chapter 3 suggests that patients diagnosed with piriformis syndrome appear just as likely as the general population to have a piriformis muscle and sciatic nerve anomaly. These results may be due to the small sample size of the surgical patients or they may present a more important concern such as the misdiagnosis of piriformis syndrome.

PRESENT STUDY

The present study data was compared to the following: adult cadaveric studies with the Eastern Asian region excluded, American adult cadaveric studies, European adult cadaveric studies, fetal cadaveric studies, and surgical studies. The results for all of these individual comparisons were found to be significantly different. Low sample size of the present study may have contributed to these results which is why future studies may want to consider increasing the sample size.

CONCLUSION

As physicians begin with a differential diagnosis for what could be causing a patient's posterior hip and buttock pain, deep gluteal syndrome should be considered first. This describes the presence of pain in the buttock caused from non-discogenic and extrapelvic entrapment of the sciatic nerve (Kulcu & Naderi, 2008). One subset of deep gluteal syndrome is piriformis syndrome, which can be caused hypertrophy of the piriformis muscle, dynamic sciatic nerve entrapment by the piriformis muscle, or an anomalous course of the sciatic nerve. Researching new methods to determine whether an anomaly exists will provide further information to aid physicians in making a more accurate diagnosis. This allows physicians to narrow their differential diagnosis and determine whether the other two causes of piriformis syndrome are responsible. If piriformis syndrome is ruled out, physicians will be forced to investigate the other etiologies of deep gluteal syndrome. As research progresses and new methods of diagnosis are developed, patients will be diagnosed and treated more accurately, which will lead to an increase in the quality of life in patient's suffering from posterior hip and buttock pain. Continuing education should be provided for physicians to inform them of the new discoveries surrounding anatomical variations and how they may be a source of pain.

The data obtained from the present study was compared in several ways to the existing data found in the primary literature. The results suggest that new methods of diagnosis need to be explored to streamline treatment as the current standards are inefficient and time consuming for physicians and patients.

For future studies, a national database containing all medical records of donors should be created to provide means for more accurate results. Additionally, standards regarding the data collected during cadaveric studies should be enforced. Suggested criteria should include age, sex, laterality, classification of variations, thorough medical history, including trauma and surgery in the gluteal region, nationality, nerve measurements, and any additional pertinent information to the research. As technology advances to study embryological development, anatomical variations and how they originate should be at the forefront of research. Focused research into fetal development will allow for a more accurate analysis between age and anatomical variation. The more research we have into this area of study, the more education we can provide to current and future physicians. As physicians are able to more accurately and efficiently diagnose the source of posterior hip and buttock pain, they will be able to treat this pain more effectively.

Worldwide chronic pain poses a serious threat to healthcare systems and overall quality of life. Continued research will be instrumental in understanding pain associated with the sciatic nerve divisions and their relation to the piriformis muscle within the subgluteal space.

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APPENDICES

APPENDIX A: INTERACTIVE DISSECTION GUIDE

#31 - Gluteal Region and Posterior Thigh

A. Clean the **gluteus maximus** (550/N477) muscle of fascia sufficiently to ascertain its borders and attachments. Bisect this muscle into two equal halves with a vertical cut slightly lateral to the posterior femoral cutaneous nerve that emerges from below its inferior border and courses deep to the fascia lata in the thigh. Reflect the cut muscle medially and laterally. Be careful not to remove the **sacrotuberous ligament** (550/N484) to which the gluteus is attached when reflecting the medial half of the muscle.

B. Locate the **piriformis muscle** (554/N484) which has been exposed by the reflection of the gluteus maximus. This muscle is the key to the gluteal region because all structures entering the gluteal region (except the obturator internus muscle) enter through the **greater sciatic foramen** (550/N484) by passing either superior or inferior to the piriformis muscle.

Verify that the piriformis itself passes through the greater sciatic foramen. The belly formed part of the wall of the pelvic cavity.

C. Identify and clean the **inferior gluteal artery and nerve** (559+561/N484). Its branches to the lateral part of the gluteus maximus have been severed by the bisection but those to the medial part will be intact.

D. Identify the **gluteus medius** (552/N485) muscle. Cut the muscle close to its attachment to the greater trochanter. Upward reflection of the muscle will reveal the **gluteus minimus** (552/N485) muscle and the **superior gluteal artery and nerve** (558+560/N484). Trace a branch of this nerve anteriorly into the tensor fascia latae.

E. Note the **sciatic nerve** (558/N484) emerging below the piriformis. Ordinarily it is a single trunk but on occasion the common peroneal division will perforate the piriformis resulting in a separation of tibial and common fibularis (peroneal) divisions throughout the length of the thigh. A small artery from the inferior gluteal may be found on the sciatic. It represents the embryonic central artery of the limb.

F. The **internal pudendal artery** (561/N484) and **pudendal nerve** (559/N485) may be found medial to the sciatic nerve and covered in part by the edge of the sacrotuberous ligament. These structures are in contact with the ischial spine, which lies anterior, and will traverse the **lesser sciatic foramen** (550/N485) to enter the perineum. Other small nerves that may be encountered in this location are those supplying the obturator internus, gemelli and quadratus femoris muscles.

G. To expose the tendon of the **obturator internus** (555/N485) after it has traversed the lesser sciatic foramen the **superior and inferior gemelli muscles** (N485) must be split, but not cut. The obturator tendon is surrounded with fibers of the gemelli.

H. The **quadratus femoris** (556/N485) lies inferior to the inferior gemellus. After locating it, cut the muscle vertically and reflect the ends. Deep to this muscle the tendon of the **obturator externus** (556/N475) will be found with the **medial circumflex artery** (546/N484) on its surface. (Try to medially rotate the limb in order to better expose these structures). A branch of this artery will ascend to the trochanteric fossa where it will enter the neck of the femur as a major supplier of the head of the femur, especially in the elderly. Note the superior border of the adductor magnus just below and anterior to the quadratus.

I. Remove the fascia lata from the posterior thigh and identify and isolate the **hamstring muscles** (565/N484) , i.e. **biceps femoris (short and long heads), semitendinosus, and semimembranosus**.

J. Follow the **sciatic nerve** (N484) distally into the popliteal fossa. Locate the branches to the hamstrings. Note the division into **common fibular (peroneal)** (N484) and **tibial nerves** (N484) unless the nerve has been split from its origin.

K. The arteries found on the posterior thigh are all derived from the anterior side. A branch of the medial circumflex may be seen entering the posterior thigh above the adductor magnus. All of the others are branches of **perforating arteries** (545/N484) from the deep artery of the thigh. Verify that the perforating arteries pass through the substance of the adductor magnus, the attachment of the short head of the biceps to the femur, and the **lateral intermuscular septum** (524/N487) to enter the vastus lateralis. They are in contact with the femur as they pass posterior to it.

APPENDIX B: BEQUETHAL FORM

Anatomical Board of the State of Nebraska

986395 Nebraska Medical Center, Omaha, Nebraska 68198-6395
Voice (402) 559-6249 Fax (402) 559-3400 pbecker@unmc.edu

Department of Biomedical Sciences
School of Medicine
Creighton University
Omaha, Nebraska 68178
(402) 280-2542

Department of Genetics, Cell Biology, and Anatomy
College of Medicine
University of Nebraska
Omaha, Nebraska 68198-6395
(402) 559-8328

Donation for Humanity

Your expressed interest in participating in the advancement of medical education and research is truly commendable. This is a significant contribution to future generations for which money cannot substitute and which perpetuates individuals' usefulness to society past their lifetime. Each participant will train no less than four new health professionals and the valuable data gained from each study may assist in advancing the treatment or alleviation of various diseases or physical afflictions. What more fitting memorial can one leave behind than a medical contribution capable of ensuring life and health for thousands, among them perhaps one's own children and grandchildren?

It is perfectly legal in the State of Nebraska for residents or non-residents to donate themselves to the Anatomical Board of the State of Nebraska. This Board is the agency with legal responsibility for the care and assignment of donors for scientific studies within medical and dental centers in Nebraska. The Board distributes the donors among the educational institutions as needed in order to make optimum use of all donors. Studies of anatomical donors are for educational and research purposes only. No legal findings will be determined and no report will be given upon completion of the study. Generally, most studies are concluded within two years. Upon completion of the study a reasonable attempt will be made to notify the donor's family. Cremated remains of a donor not claimed within one year following the notification, or the attempted notification, of the donor's family will be interred or entombed in a common plot owned by the designated university in an Omaha cemetery.

Enclosed are several pages of instructions which provide detailed information on the body donation program. Should you decide to participate in the advancement of medical science and education this way, please complete the enclosed forms and return them for enrollment. A formal will is not required for the donation of one's self; however, the Certificate of Bequeathal must be returned to the Board for acceptance before the enrollment is completed. A wallet card will be mailed to the donor upon acceptance into the program. Donors who have not completed the enrollment will not be accepted. You are strongly advised to consult with your relatives, physician, minister, lawyer or any party responsible for your affairs so they may know your wishes.

Instructions for Donor

(Keep this page for your records)

1. Occasionally a problem may exist which would interfere with the intended use of a donor's gift for education and research. The body may not be accepted if any of the following conditions are present: autopsy, organs or parts removed for transplantation (with the exception of eyes), decomposition of the body, severe trauma, drowning, burning, homicide, motor-vehicle accident, death from suicide, contagious disease such as HIV or Hepatitis B or C, morbid obesity, emaciation, body contracture, jaundice, edema or a body mass index less than 19 or greater than 30. The Board also cannot receive donors when storage is full.

2. a. **Complete the Certificate of Bequeathal** and sign in the presence of two witnesses (not members of your family). In the State of Nebraska it is desirable that agreement and consent of next-of-kin be obtained. Since other states may specify agreement and consent of close relatives, out-of-state donors should be certain to obtain the consent of all the closest next-of-kin on the Certificate of Bequeathal.

   b. **Make two copies of the Certificate of Bequeathal.**
      - **Place one copy with readily available personal papers.** (A bank safe deposit box is <u>not</u> recommended.)
      - **Provide one copy of the Certificate of Bequeathal** to a member of the family, close friend, or attorney who will attend to all arrangements in sending the donor to the Nebraska Anatomical Board. Also, provide them with a copy of the "Instructions to Survivors" page which follows.
      - **Return the original Certificate of Bequeathal with requested information to the Nebraska Anatomical Board for enrollment in the program. Regardless of college preference, send the Certificate of Bequeathal to:** Anatomical Board of Nebraska, 986395 Nebraska Medical Center, Omaha, NE 68198-6395.

3. ALTHOUGH NOT ESSENTIAL, the donor may elect to make advance arrangements with a funeral director in the vicinity. The funeral director should be informed of donors' plans to dedicate themselves to medical science and be instructed as to his responsibilities. (See "Instructions to Survivors.")

   The Board has no facilities available for viewing the donor. A mortuary of the family's choice should be contacted if the donor or their survivors wish to hold a viewing, a visitation and/or a funeral service before the delivery to the Nebraska Anatomical Board. **The cost of these services must be assumed by the donor's estate or family members.**

4. A brief Medical History is of great value in medical school teaching and research programs; a form for this purpose is enclosed. **Return the MEDICAL HISTORY page with the original Certificate of Bequeathal.**

5. After the study is completed, the cremated remains will either be interred in a common plot owned by the university or returned to the designated family member, mortuary, or cemetery. The arrangements for the final disposition of the donor's cremated remains are contained in paragraph 3 of "Instructions to Survivors."

6. A wallet card will be sent to the donor upon the completed enrollment into the Nebraska Anatomical Deeded Body Program. Enrollment is **required** before a donor can be accepted. This card should be carried by the donor at all times.

7. **Your financial support can also help advance education and research in the health sciences at both the University of Nebraska and Creighton University**. Please send your tax deductible contribution to the following address: **Research and Development Fund, Anatomical Board of the State of Nebraska, 986395 Nebraska Medical Center, Omaha, NE 68198-6395.**

(Rev. 09/12)

<u>Instructions for Survivors</u>

(To be given to a family member, close friend or attorney)

1. The Nebraska Anatomical Board or your local funeral director will expedite the completion of all the necessary papers, such as filing the death certificate. Donors are accepted to age 110 and all donors stay in Nebraska.

2. The Board cannot accept a donor which has been autopsied. The Nebraska Anatomical Board has **no** facilities available for viewing the donor; the donor must be transferred within 12 hours to the Nebraska Anatomical facility. If no viewing/visitation/funeral arrangements are planned, transportation arrangements can be made through one of the following procedures:

   a) If death occurs in Lincoln or within a 60-mile radius of Omaha and there is no funeral, contact the Nebraska Anatomical Board anytime at (402) 559-6249 or the pager at (402) 888-3965.

   b. If there will be a funeral and/or a death occurs beyond a 60 miles radius of Omaha, contact a funeral director of your choice. <u>Be sure to inform the funeral director that you have a donor for the Nebraska Anatomical Board</u>. The funeral director will make arrangements for delivery to the Nebraska Anatomical Facility.

   NOTE: **Body donation may involve expense for the donor's estate or survivors whether elected by survivors or required by circumstance.** If death occurs within a 60-mile radius of Omaha and the body is delivered to the Nebraska Anatomical Board within 12 hours of the death, there may be little to no expense. However, expenses may occur depending if a mortuary is involved and its particular policies. Beyond the 60-mile radius of Omaha or Lincoln city limits, or if delivery of the donor will require more than 12 hours, additional arrangements must be made with a mortuary. The Nebraska Anatomical Board reimburses mortuaries \$110 for removal from the place of death in Nebraska and Iowa and **for mileage** at the rate of \$1.50 per mile one way, up to 250 miles from the place of death. It is important that survivors have a clear understanding of expenses involved when they make arrangements with a mortuary.

   Families of potential donors are advised that the Nebraska Anatomical Board <u>may not</u> accept all donations. The Board retains the right to refuse donors deemed unsuitable for current needs for education and research.

3. After completion of the study, which generally lasts from six months to two years, the human remains will be cremated with dignity and respect. There are several available choices regarding the final disposition of the donor:

   a) If requested to do so, the Nebraska Anatomical Board will return the human cremated remains at the expense of the university in a suitable container to the designated relative, mortuary, or cemetery for final disposition. Any and all costs of final disposition after the cremated remains are received by the designated party must be borne by the estate or survivors of the deceased. Cremated remains of a donor not claimed within one year following the notification, or the attempted notification, of the donor's family will be interred or entombed in a common plot owned by the designated university in an Omaha cemetery.

   b) If no such request is made, upon completion of the study, the human cremated remains will be interred or entombed by the Nebraska Anatomical Board in a common plot owned by the designated university in an Omaha cemetery.

Body Mass Index Information

Listed below is a summary of the acceptable weights for your height in inches to be an eligible donor for the Nebraska Anatomical Board.

Height		Weight
4 ft – 10 in	(58 inches)	91 to 143 lbs.
4 ft – 11 in	(59 inches)	94 to 148 lbs.
5 ft	(60 inches)	97 to 153 lbs.
5 ft –1 in	(61 inches)	100 to 158 lbs.
5 ft – 2 in	(62 inches)	104 to 164 lbs.
5 ft – 3 in	(63 inches)	107 to 170 lbs
5 ft – 4 in	(64 inches)	110 to 175 lbs.
5 ft – 5 in	(65 inches)	114 to 180 lbs.
5 ft – 6 in	(66 inches)	118 to 186 lbs.
5 ft – 7 in	(67 inches)	120 to 191lbs.
5 ft – 8 in	(68 inches)	125 to 197 lbs.
5 ft – 9 in	(69 inches)	128 to 203 lbs.
5 ft – 10 in	(70 inches)	132 to 209 lbs.
5 ft – 11 in	(71 inches)	136 to 215 lbs.
6 ft	(72 inches)	140 to 220 lbs.
6 ft – 1 in	(73 inches)	145 to 227 lbs.
6 ft – 2 in	(74 inches)	148 to 233 lbs.
6 ft – 3 in	(75 inches)	152 to 240 lbs.
6 ft – 4 in	(76 inches)	156 to 246 lbs.

(Rev. 09/12)

Anatomical Board of the State of Nebraska

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University of Nebraska
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(402) 559-8328

Certificate of Bequeathal and Cremation Authorization

(Return this page)

I, ____ hereby express my wish to donate my body following my death to the Anatomical Board of the State of Nebraska. I understand that this is a statement of my wish and intention to dedicate myself to medical education and scientific research in the state of Nebraska. In order that this wish may be carried out promptly and effectively after my death, I accept responsibility for obtaining the consent of all relatives or close friends likely to have concerns about the cremation and final disposition of my body. I also authorize the release of my medical records to the Anatomical Board of Nebraska.

I have indicated my preference below for the location of the study, however, I understand the Board may assign my body to the university where needed in order to make optimum use of all donors. Creighton University, the University of Nebraska and the Anatomical Board will make a reasonable effort to respect my preference.

_____ The University of Nebraska
_____ Creighton University
_____ No Preference

Signed ____

Address ____

City ____

State ______________ Zip _________________________

Date ____

Phone (_______) _______________________________

Witness ___________________________________

Witness ___________________________________
(Witnesses should not be members of your family)

(Rev. 09/12)

(Return this page)

Endorsements of Family: We understand and support the intent indicated in this Certificate of Bequeathal and agree to cremation of the donor in accordance with applicable laws and regulations.

Name	Address	Relationship	Date Signed

If it is a burden for family members to sign above and they support your decision for donation and cremation, check the boxes below after you have contacted them.

Are there any other close relatives (spouse, parents, grown children, brothers or sisters) who have not signed? Yes ____ No____

Will they respect the donor's wishes and honor the bequeathal and cremation? Yes ____ No ____

PLEASE CHOOSE THE FINAL DISPOSITION OF HUMAN CREMATED REMAINS:

1. INTERMENT by the Nebraska Anatomical Board at a cemetery chosen by:

   Creighton University or The University of Nebraska

2. RETURN the human cremated remains of the donor to: FAMILY MORTUARY CEMETERY

Please indicate address: ____

____

Notification of Memorial Service: Each year the students from each medical center hold a memorial service to honor donors who have contributed to their education. Families who want to be invited to the memorial service after the study has been completed should indicate below.

Notify family member of memorial service after study is completed? Yes _____ No_____

Name of person to notify:

____

Name Address Phone Number

____

Email

Next of kin or person in charge of donor's affairs:

____

Name Address Phone Number

____

Email

(Before returning the bequeathal form, make a copy of both sides for a family member, close friend or attorney and one for your records.)

(Rev. 09/12)

BRIEF MEDICAL HISTORY

(Return this page)

Please Print

Height: _______ Ft. _______ In. **Weight** _______ lbs. (*required*)

Disease History (*childhood diseases, heart, kidney, etc.*):

Operation and Accident History:

Disabilities or Deformities:

(Rev. 09/12)

DEATH CERTIFICATE INFORMATION

(Return this page)

Please Print

Name: Last ______________________________

First ______________________________

Middle ______________________________

Sex: _______

Date of Birth: ______________________________

Social Security Number: __________ ________ __________

City and State of Birth: ______________________________

Primary occupation prior to retirement: ______________________________

Marital Status (*circle one*): **Never Married** **Married** **Widowed** **Divorced**

Name of Surviving Spouse: ______________________________

If wife, give Maiden Name: ______________________________

Father's Name: ______________________________

Mother's Name, including **Maiden** Name: ______________________________

Dates of Military Service (*if applicable*): _____ _____ _______ to _____ _____ _______
Month Day Year Month Day Year

Education: (0-12 years) _________ **College** (# of years) _________ **Degree** ___________

Current Doctor - ***Name and Address***: ______________________________

____

Please mail completed pages for enrollment to:

The Nebraska Anatomical Board
986395 Nebraska Medical Center
Omaha, NE 68198-6395

(Rev. 09/12)

APPENDIX C: PRESENT STUDY SOURCE DATA

Table 18: Source data obtained during the present study.

Table #	Sex	Age	Right	Left	Notes
1	M	75	Type A	Type A	
2	F	77	Type A	Type A	
3	M	84	Type A	Type A	
4	M	82	Type A	Type A	
5	F	76	Type A	Type A	
6	M	78	Type A	**Type B**	
7	F	81	Type A	Type A	
8	M	82	Type A	Type A	
9	F	74	Type A	Type A	
10	F	100	Type A	Type A	
11	M	97	Type A	Type A	
12	M	81	Type A	Type A	
13	F	76	Type A	Type A	
14	F	80	Type A	Type A	
15	M	88	Type A	Type A	
16	F	87	Type A	Type A	
17	M	76	Type A	Type A	
18	F	88	Type A	Type A	
19	M	90	Type A	Type A	
20	M	67	Type A	Type A	
21	F	69	Type A	Type A	
22	F	94	Type A	Type A	
23	M	84	Type A	Type A	
24	F	73	Type A	Type A	
25	F	75	Type A	Type A	
26	F	75	**Type B**	Type A	
27	M	80	Type A	Type A	
28	M	87	Type A	Type A	
29	F	44	Type A	Type A	
30	M	99	N/A	N/A	No table 30 data (dissection not initiated on the lower limb)
31	M	92	Type A	Type A	
32	F	96	Type A	Type A	
33	F	92	Type A	**Type B**	
34	F	90	Type A	Type A	
35	F	89	Type A	Type A	
36	M	80	Type A	Type A	
37	M	67	Type A	Type A	
38	M	81	Type A	Type A	

39	F	95	Type A	Type A	
40	M	87	Type A	Type A	
41	M	68	Type A	Type A	
42	F	58	Type A	Type A	
43	M	77	Type A	Type A	
44	F	82	Type A	Type A	
45	M	60	Type A	Type A	
46	F	70	Type A	Type A	
47	M	92	Type A	Type A	
48	F	85	Type A	Type A	
49	M	78	Type A	Type A	
50	M	89	Type A	Type A	
51	M	93	Type A	Type A	
52	F	95	Type A	Type A	
53	M	76	Type A	Type A	
54	F	61	Type A	Type A	
55	F	69	Type A	Type A	
56	F	72	Type A	Type A	
57	M	71	Type A	Type A	
58	F	87	Type A	Type A	
59	M	86	Type A	Type A	
60	M	71	Type A	Type A	
61	F	87	Type A	Type A	